NEW

HOW IT WORKS BOOK OF

SPACE

Everything you want to know about the universe we live in

OVER 1000 AMAZING FACTS

Inside the star that keeps us alive

How will we travel through space?

Relive the solar eclipse

Exploring Jupiter

Life in space

Space engineering

A tour of the ISS

What causes supernovas?

Discover NASA's Mars rovers

How telescopes work

Digital Edition

FUTURE

TWELFTH EDITION

SOLAR SYSTEM EXPLORATION UNIVERSE ASTRONOMY

Welcome to

HOW IT WORKS

BOOK OF

SPACE

Space has fascinated mankind from the earliest days of civilization, and as we keep scratching the surface of the vast universe in which we live, our sense of awe and wonder continues to grow unabated. Now, with the technological advancements being made by the world's space agencies, we understand more than ever about the things that are happening beyond our own planet. This new edition of the **How It Works Book of Space** has been updated with more of the latest astronomical advancements, stunning space photography from the most advanced telescopes on the planet, and glimpses at what the future of space exploration holds, taking you from the heart of our Solar System and out into deep space. Get ready for lift off and discover the depths of our universe and beyond with extreme cosmic temperatures, parallel universes and known active galaxies.

HOW IT WORKS BOOK OF SPACE

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Part of the HOW IT WORKS bookazine series

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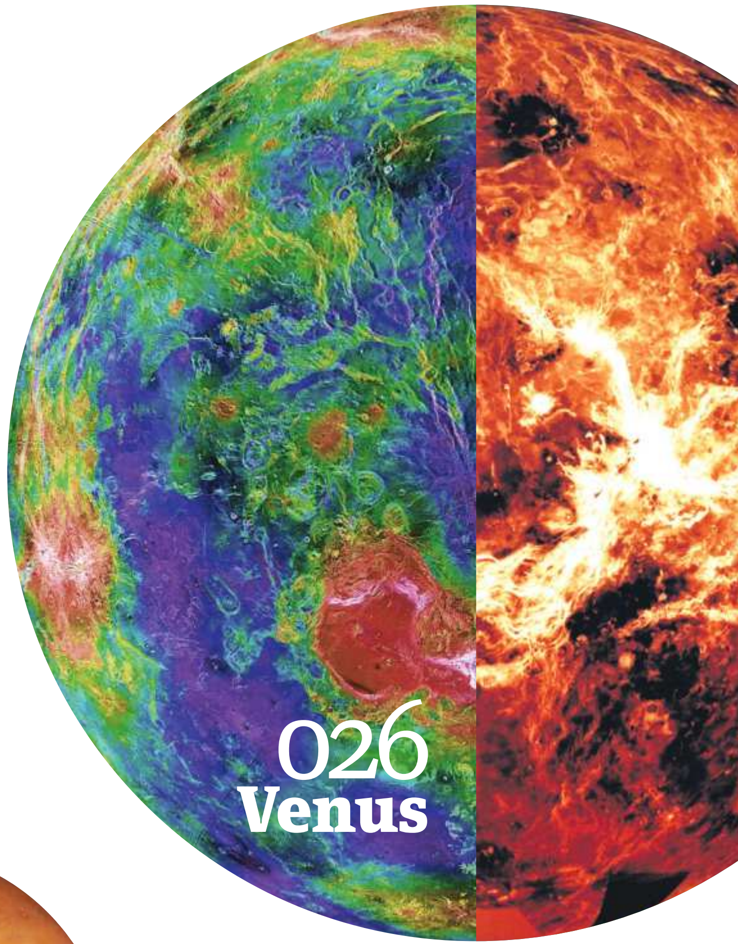

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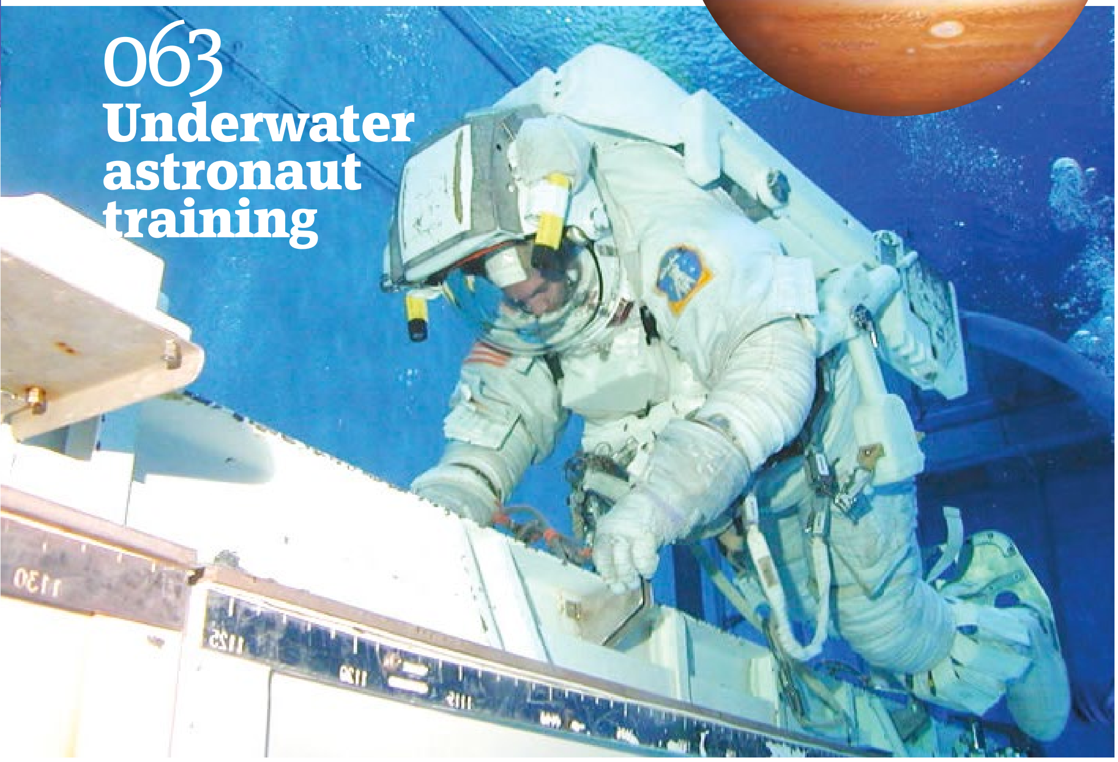

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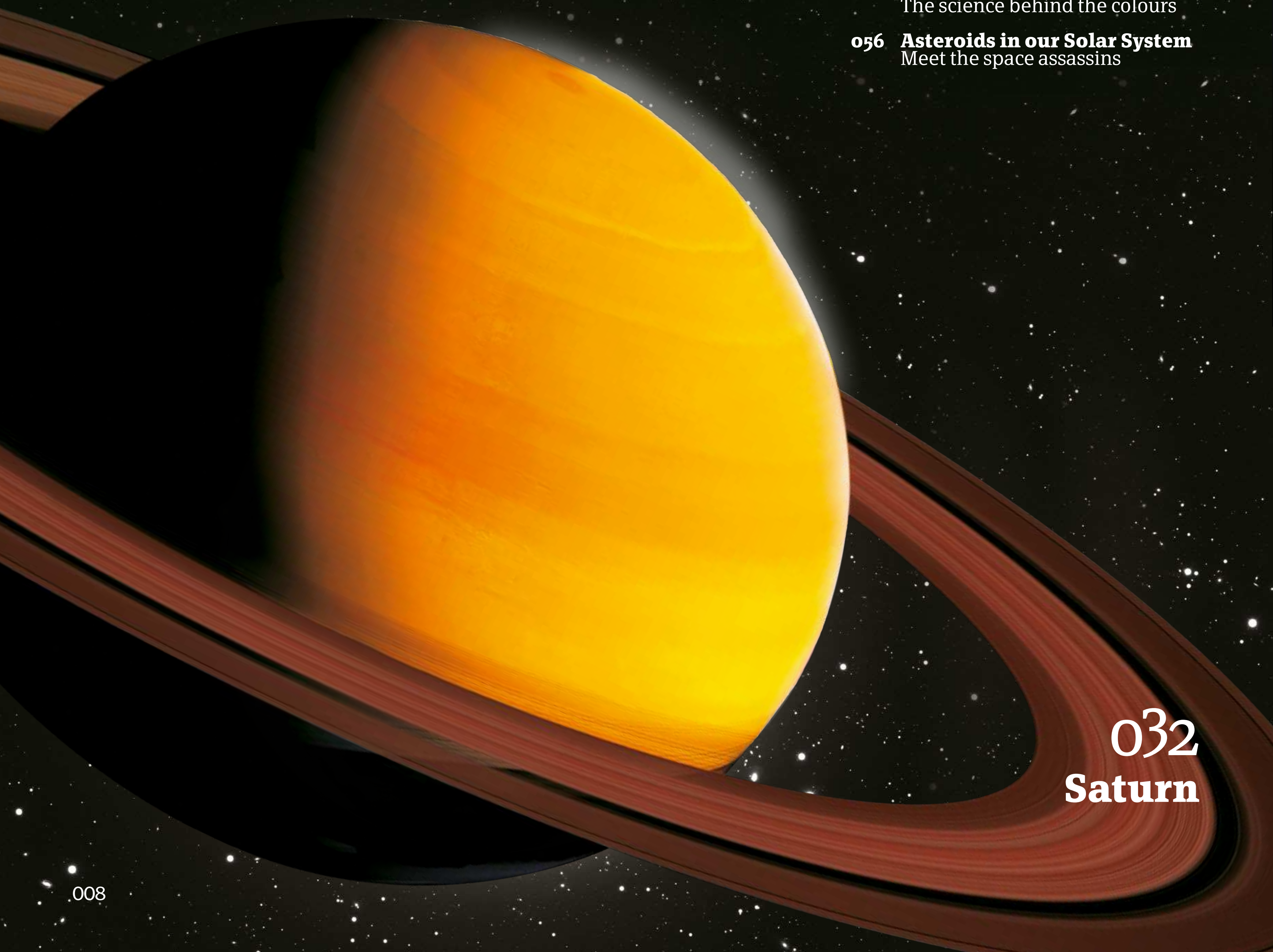

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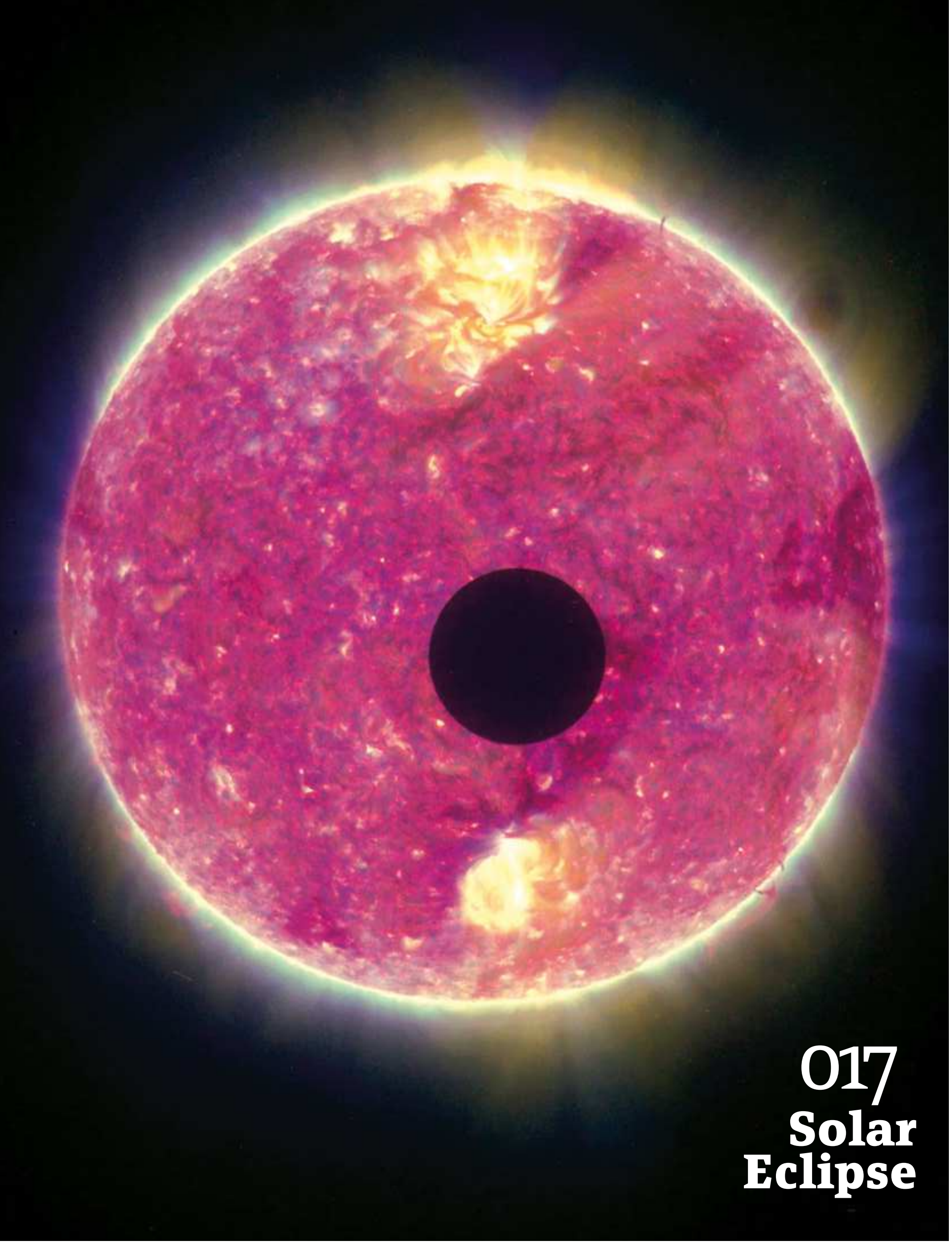
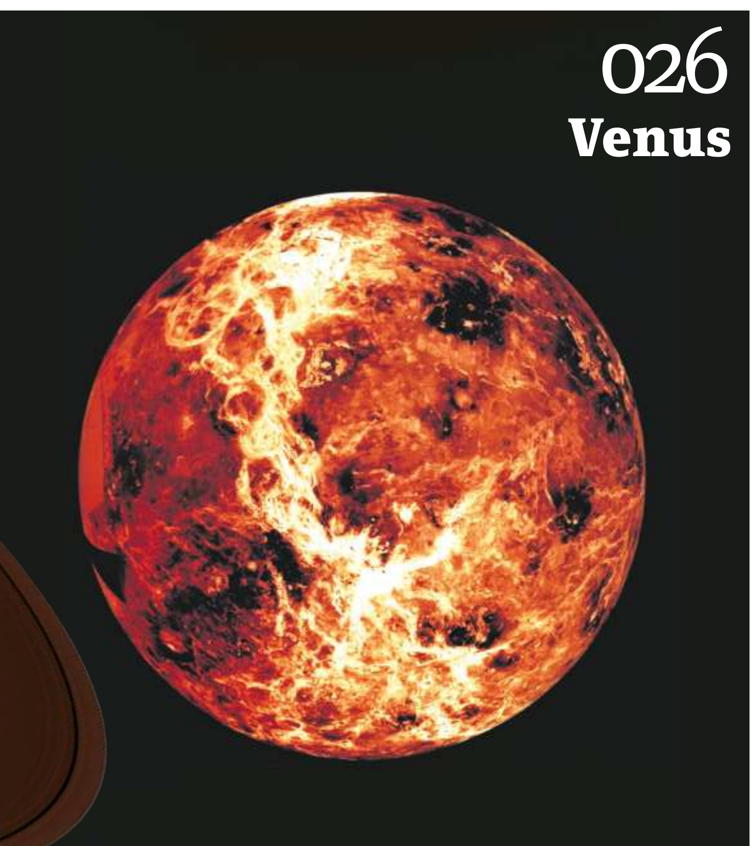
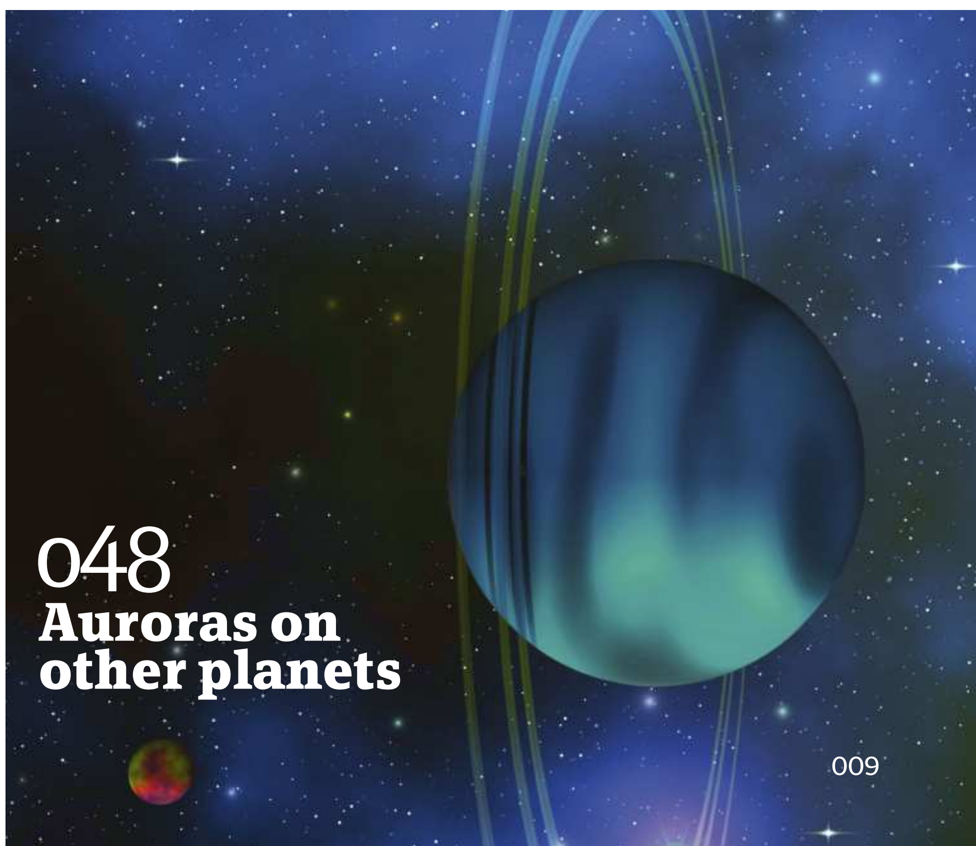






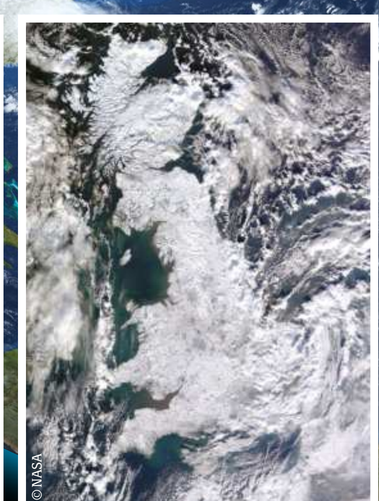
Earth

From astronaut snaps taken with handheld cameras to advanced satellite imagery that enables us to predict natural disasters, discover the planet as you've never seen it before

Spectacular aspect of the Great Barrier Reef

© NASA

© NASA



© NASA

On Christmas Eve 1968, the crew of Apollo 8 captured this unique view of Earth. Known as 'Earthrise', this photo of Earth rising over the lunar horizon was humankind's first glimpse of the Earth from deep space

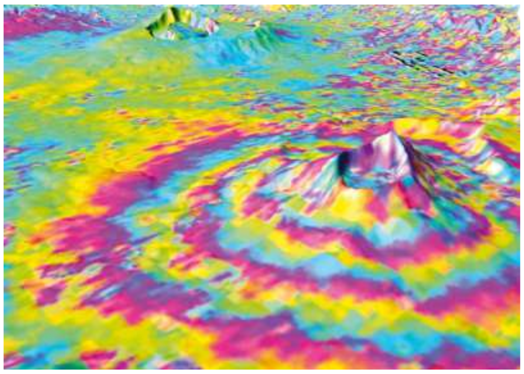
© NASA


Aurora australis taken from the ISS

© NASA

ESA's Envisat

The European Space Agency's environmental satellite (Envisat) was launched into a polar orbit on 1 March 2002. Its instruments are used to study the ocean, agriculture, ice formations and atmospheric conditions of Earth.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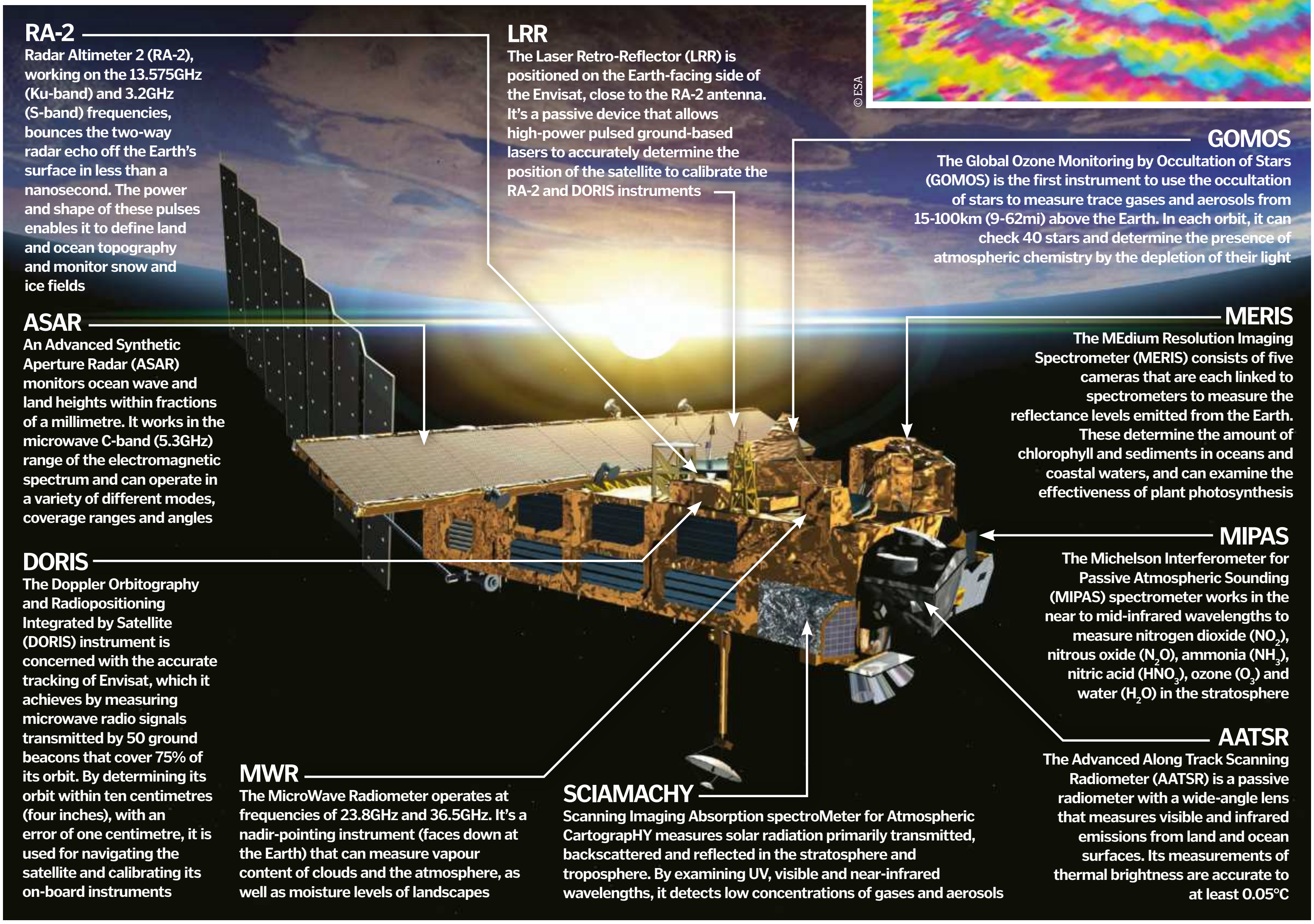


The crew of Apollo 8 were the first people to see and photograph our planet as a globe in its entirety. During the fourth orbit around the Moon, Lunar module commander William Anders took a series of photographs of the Earth that became known as 'Earthrise'. They revealed the true splendour of our planet suspended in stark contrast with the barren lunar surface, and became an icon for showing that our home is a fertile and fragile dot of life in an immense and deadly universe.

From the Sixties onwards an enormous number of Earth observation satellites have been launched to look at the hard facts about the state of our global environment, as it is assaulted by extremes of natural events and the impact of human activities.

Observations from space can study large patterns of change throughout the Earth's surface and in the atmosphere, and can be used to supplement information gained by ground or ocean-going instruments. The additional benefit of satellites is they can transmit data continuously, and cover areas of the Earth that are inaccessible or too hostile for any other methods of gaining information.

At first, Earth observation satellites simply used visible light and infrared sensors to monitor the position of clouds for weather forecasting. Later, microwave sensors were introduced to improve these forecasts by obtaining measurements of the temperature, pressure and humidity in different layers of the atmosphere.

The success of such satellites led NASA to launch the Landsat series of observation satellites in July 1972. Using multi-spectral scanner instrumentation, Landsats were able to produce images of the Earth's surface gained from up to eight different wavelengths, showing the distribution of snow and ice cover, vegetation, landscapes, coastal regions and settlements, which proved to be a rich source of new data for cartography, geology, regional planning, forestry, climate studies and educational purposes.

In the Seventies, Landsat data about the worldwide state of wheat crop growth was used to forecast yield rates and stabilise the market for this crop, which led to more stable prices for consumers. Using data from Landsat images, researchers recently discovered 650 previously unknown barrier islands, including a chain of 54 islands that stretch 563km (350mi) from the mouth of the Amazon River.

Satellites save lives and reduce property damage by tracking and warning of the arrival of hurricanes, tornadoes, floods and other extremes of weather or natural disaster. For example, in August 2005 satellites provided an accurate early warning of the approach of Hurricane Katrina

and, a month later, Hurricane Rita. Unfortunately, responses to these warnings were slow, resulting in extensive damage and loss of life. Afterwards, satellites (NASA's TRMM and NOAA's GOES and POES) provided imagery of the damaged areas to help in the reconstruction of the areas affected. This helped bring about the pledge by nations that operate satellites to provide imagery to any nation affected by a major disaster under the terms of the International Disaster Charter.

The sensing technologies used by satellites consist of optical sensors that can detect the strength of reflections from the Earth in the visible/near infrared spectrum and thermal infrared rays that are radiated from the surface. Microwave sensors can detect radiation in this longer wavelength of the spectrum coming from the Earth's surface, or active microwave sensors can send microwaves to the Earth and observe their reflections.

Civilian Earth observation satellite surveillance is co-ordinated by the committee on Earth observation satellites (CEOS), which is currently affiliated to agencies that are operating 116 active satellites. These broadly study the long-term and changing global environment from the atmosphere, land, ice and snow, oceans, gravity and magnetic fields to the oceans. In the next 15 years, CEOS agencies are planning 260 satellites, which will carry 400 instruments to develop better weather forecasting and knowledge of climate changes.

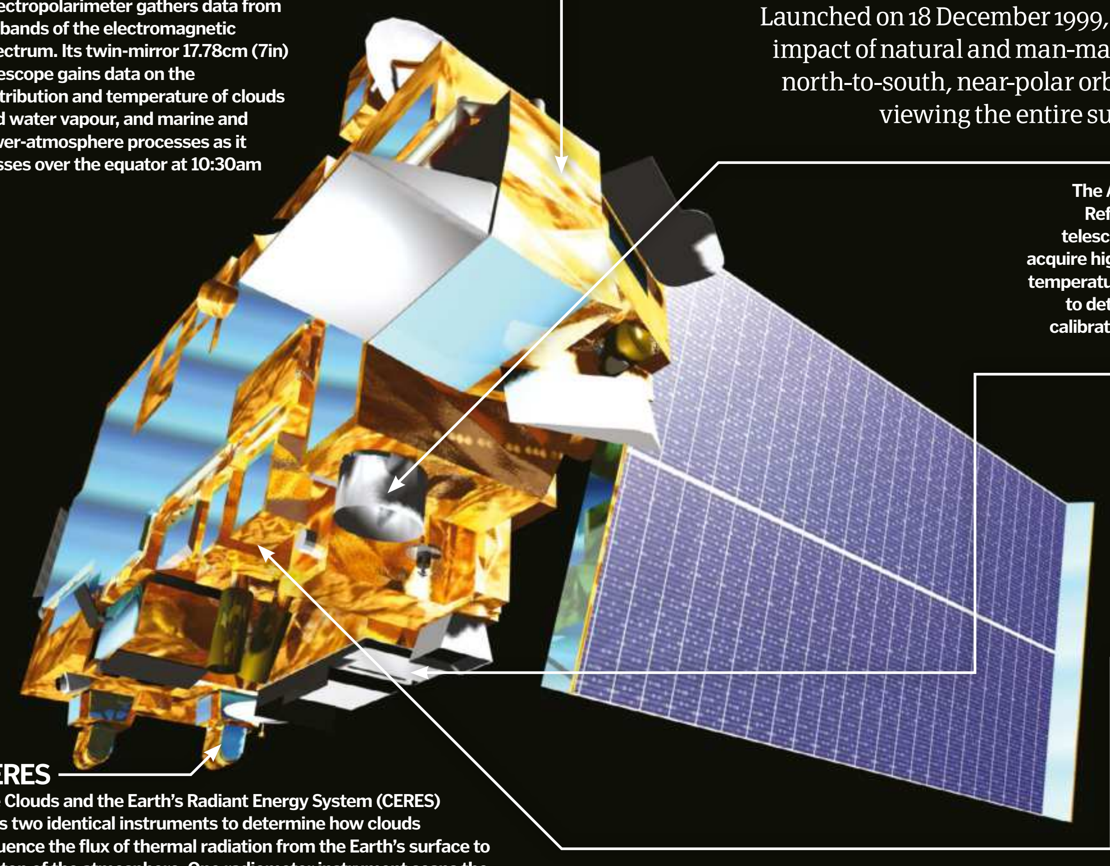
Since the Nineties, NASA has run the Earth observing system (EOS) program that co-ordinates the activities of its polar-orbiting satellites to study "radiation, clouds, water vapour and precipitation; the oceans; greenhouse gases; land-surface hydrology and ecosystem processes; glaciers, sea ice and ice sheets; ozone and stratospheric chemistry and natural and anthropogenic aerosols." To further this research, it plans to launch 15 Earth observation satellites by 2020. The European Space Agency also plans several 'Earth explorer' missions, which includes the launch of three satellites in 2013 to study the Earth's magnetic field ('Swarm') and one to profile global winds (ADM-Aeolus).

NASA's range of satellites in their Earth observing system (EOS) program includes Terra and a planned launch of Aquarius in June 2011, to measure the salt levels of our oceans. Overall, they cover every aspect of surface and atmospheric environmental conditions

"To further this research, it plans to launch 15 Earth observation satellites"

NASA's Terra satellite

Launched on 18 December 1999, Terra (EOS AM-1) investigates the impact of natural and man-made climate changes. It travels in a north-to-south, near-polar orbit at an altitude of 705km (438mi), viewing the entire surface of the Earth every two days



MODIS
The MODerate-resolution Imaging Spectropolarimeter gathers data from 36 bands of the electromagnetic spectrum. Its twin-mirror 17.78cm (7in) telescope gains data on the distribution and temperature of clouds and water vapour, and marine and lower-atmosphere processes as it passes over the equator at 10:30am

ASTER
The Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER) consists of three telescopes that during eight minutes of every orbit acquire high-resolution images of land heights, surface temperatures, emissions and reflections. They are able to detect changes in land surfaces and are used to calibrate data gained by the other Terra instruments

MISR
The Multi-angle Imaging Spectro-Radiometer (MISR) uses nine digital cameras pointing at different angles to obtain images in the blue, green, red and near-infrared wavelengths of the electromagnetic spectrum. They are able to provide monthly trends in the distribution of aerosol particles, cloud formations and seasonal vegetation changes

MOPITT
The Measurements Of Pollution In The Troposphere (MOPITT) instrument package measures the amount of carbon monoxide (CO) in the troposphere by analysing infrared radiation vertically radiating from the Earth. These measurements enable the production of models of the composition and distribution of fossil fuel consumption and biomass burning on a global scale

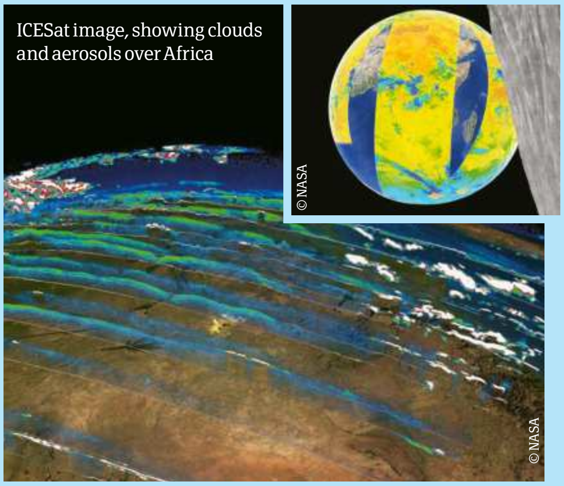
CERES
The Clouds and the Earth's Radiant Energy System (CERES) uses two identical instruments to determine how clouds influence the flux of thermal radiation from the Earth's surface to the top of the atmosphere. One radiometer instrument scans the Earth across the track of the satellite and the other scans along it

© NASA

Which aspects of Earth are the satellites observing?

Atmosphere

NASA launched eight Nimbus Earth observation satellites between 1964 and 1978. They pioneered the use of 'sounders' that measure the humidity and temperature of the atmosphere. They obtain temperature measurements by analysing infrared radiation (IR) on wavelengths linked with oxygen or carbon dioxide. IR or microwave sounders identify water vapour in the atmosphere to measure humidity. Microwave sounders have a lower resolution, but can be used in all weather conditions as they can sound through clouds.



ICESat image, showing clouds and aerosols over Africa

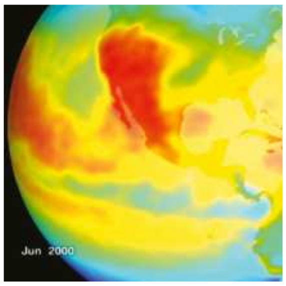
© NASA

© NASA

Gulf oil spill creeps towards the Mississippi Delta

Oceans

In the Seventies the USA and USSR ran ocean observation satellite programmes, which carried synthetic aperture radar (SAR) equipment. A number of radar images are taken by SARs and combined to produce a single detailed image. This is able to determine the height of sea levels, waves, currents and their distribution and can detect oil slicks and shipping movements. The Jason 1 and 2 spacecraft currently use these techniques to study the topography and characteristics of the oceans, to give a better warning of floods or climate changes.



The red portion of this view of the US reveals the highest ground levels of ultraviolet radiation

Radiation

Visible blue, green and red light only provides a limited amount of information about the Earth's surface, so satellites use spectrometers to study the invisible near-infrared and infrared parts of the electromagnetic spectrum.

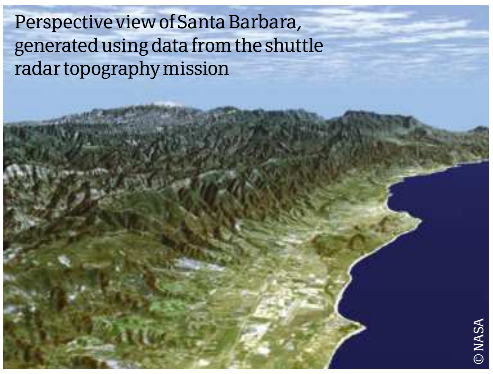
They can identify and track the growth of plant species, as they all reflect infrared light. The infrared 'fingerprint' of plants can also indicate the amount of water present and can warn of potential droughts. Likewise, exposed rocks radiate their own infrared fingerprint that allows geologists to identify valuable mineral/oil deposits.

Infrared data from satellites is 'false coloured', so invisible light from up to three wavelengths is rendered into a combination of visible red, green and blue.

Land

The Shuttle Radar Topography Mission (SRTM) by the Endeavour space shuttle in February 2000 used two radar antennas to produce the most comprehensive hi-res digital topographical map of the Earth's terrain. The data is used by Google Earth to create maps that can be viewed in 2D or 3D.

Earth observation satellites are important in monitoring the seasonal variation of vegetation. Besides studying long-term changes, they are also used to observe and issue warnings of natural disasters such as volcanic eruptions, forest fires and earthquakes.



Perspective view of Santa Barbara, generated using data from the shuttle radar topography mission

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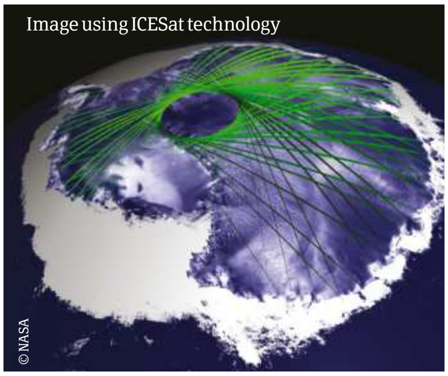

Image using ICESat technology

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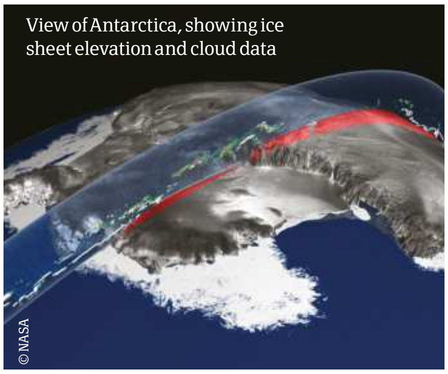


View of Antarctica, showing ice sheet elevation and cloud data

© NASA

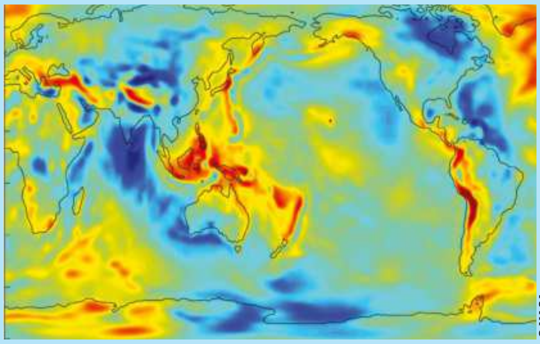
Ice

Carrying on from the work of Envisat, which discovered that every decade since 1978 the Arctic ice fields have shrunk by 2.7%, the European Space Agency launched CryoSat-2 on 8 April 2010. It uses radar altimeters with SAR technology, specifically designed for its mission to study the thickness and distribution of ice in the polar oceans. NASA's ICESat (2004) carried a Geoscience Laser Altimeter System (GLAS), which used pulses of laser light to measure the height and characteristics of Greenland and Antarctic ice fields. These satellites have indicated the role of greenhouse gases in the polar atmosphere and that the ozone layer has shown signs of recovery.

Gravity

The European gravity field and steady-state ocean circulation explorer (GOCE), launched in March 2009, carries an Electrostatic Gravity Gradiometer (EGG) to measure the gravity field of Earth. By measuring the minute variations in the tug of gravity, it enables the production of Geoid maps of the globe that can indicate ocean circulation and changes, the movement and composition of polar ice sheets and the physics of the Earth's interior.

In March 2002, NASA launched two Gravity Recovery And Climate Experiment (GRACE) spacecraft. They use a microwave system that accurately measures any minute changes between their speed and distance, indicating the influence of the Earth's gravitational pull.



© NASA

Inside the Sun

The giant star that keeps us all alive…

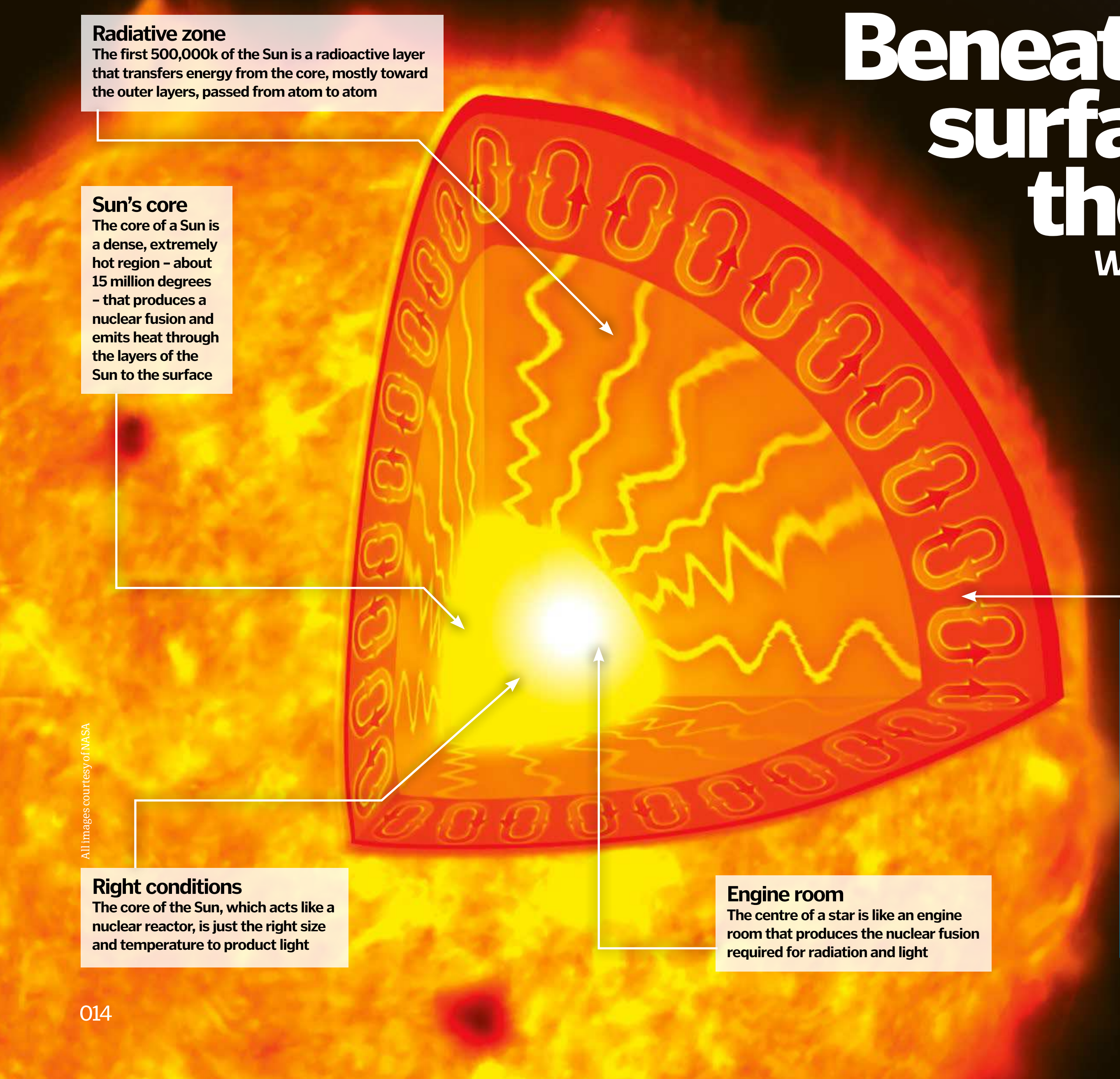
A celestial wonder, the Sun is a huge star formed from a massive gravitational collapse when space dust and gas from a nebula collided, It became an orb 100 times bigger and weighing over 300,000 times that of Earth. Made up of 70 per cent hydrogen and about 28 per cent helium (plus other gases), the Sun is the centre of our solar system and the largest celestial body anywhere near us.

"The surface of the Sun is a dense layer of plasma at a temperature of 5,800 degrees kelvin that is continually moving due to the action of convective motions driven by heating from below," says David Alexander, a professor of physics and astronomy at Rice University. "These convective motions show up as a distribution of what are called granulation cells about 1,000 kilometers across and which appear across the whole solar surface."

At its core, the Sun's temperature and pressure are so high and the hydrogen atoms are moving so fast that it causes fusion, turning hydrogen atoms into helium. Electromagetic radiation travels out from the Sun's core to its surface, escaping into space as electromagnetic radiation, a blinding light, and incredible levels of solar heat. In fact, the core of the Sun is actually hotter than the surface, but when heat escapes from the surface, the temperature rises to over 1-2 million degrees. Alexander explained that astronomers do not fully understand why the Sun's atmosphere is so hot, but think it has something to do with magnetic fields.

Beneath the surface of the Sun

What is the Sun made of?



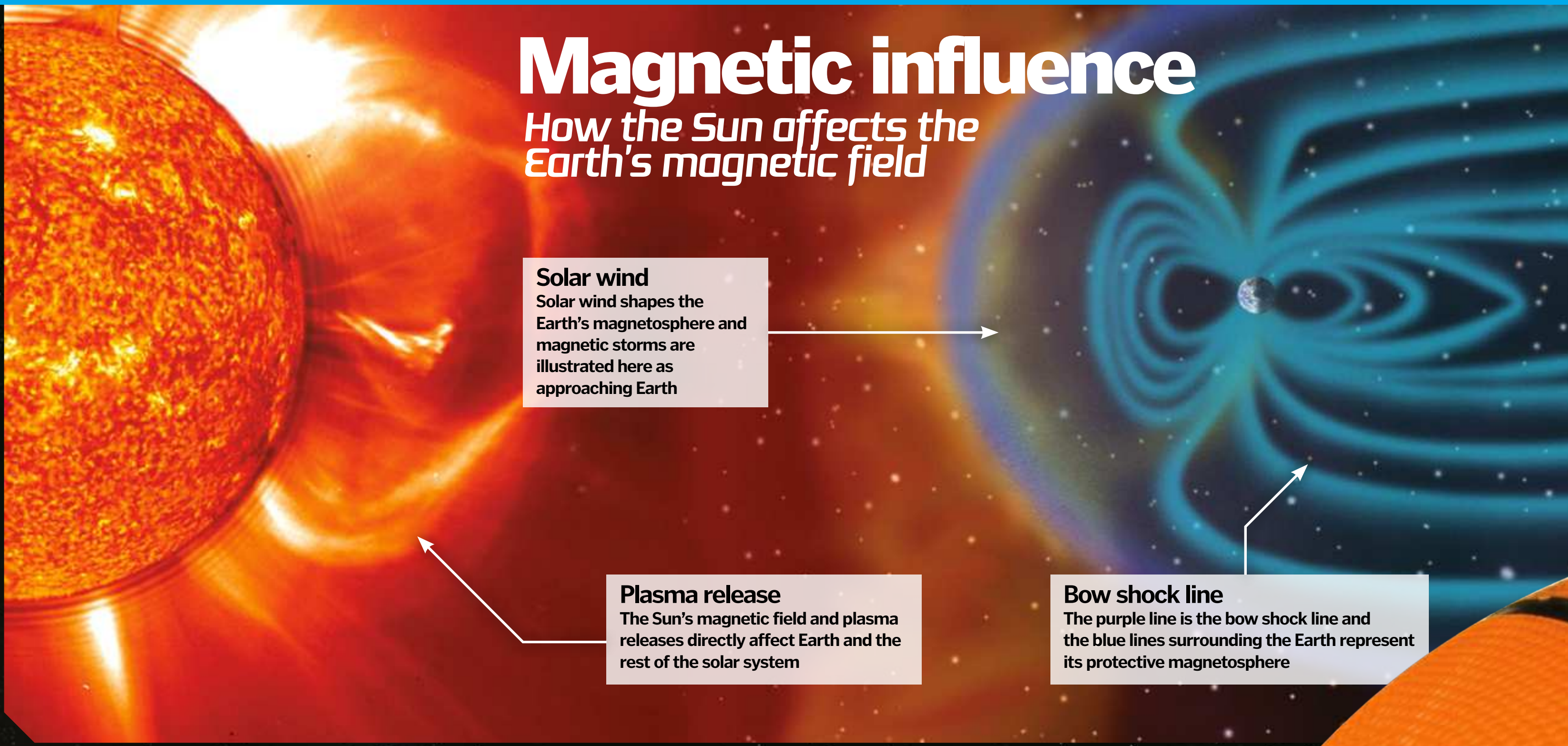
The Statistics

The Sun

Diameter: 100 times Earth
Mass: 300,000 times Earth
Average surface temp: 1-2 million degrees
Core temp: 15 million degrees

Magnetic influence

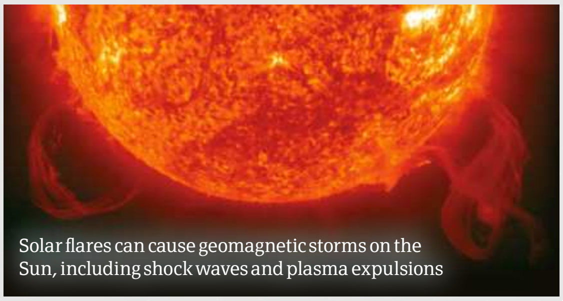
How the Sun affects the Earth's magnetic field



What is a solar flare?

A massive explosion, but one that happens to be several million degrees in temperature…

"A solar flare is a rapid release of energy in the solar atmosphere (mostly the chromosphere and corona) resulting in localised heating of plasma to tens of millions of degrees, acceleration of electrons and protons to high energies, some to near the speed of light, and expulsion of material into space," says Alexander. "These electromagnetic disturbances here on Earth pose potential dangers for Earth-orbiting satellites, space-walking astronauts, crews on high-altitude spacecraft, and power grids on Earth."


Solar flares can cause geomagnetic storms on the Sun, including shock waves and plasma expulsions

Solar eclipses

When the Moon blocks out the Sun

A solar eclipse is a unique phenomena where the Moon passes directly into a line between the Earth and the Sun, partially or completely blocking our view of the Sun. The Sun is blocked according to the relative orbits of each celestial body. There are two kinds of eclipses: one where the Moon orbit shows the outer edge of the Sun, or where the Moon lines up perfectly and the Sun is blocked completely from view.


Sometimes, the orbits of the Earth and Sun line up perfectly so that the Sun is blocked (eclipsed) by the Moon, shown here with a shadow cast from the eclipse, taken from the ISS

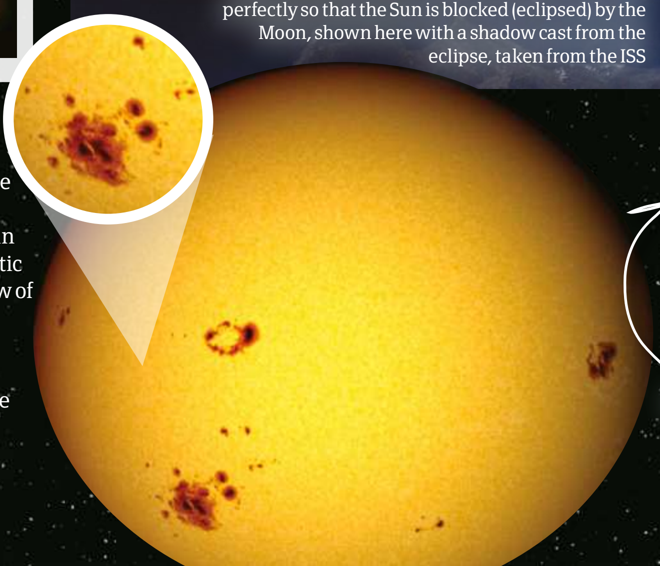
How big is the Sun?

Our Sun has a diameter of 1.4 million km and Earth a diameter of almost 13,000km

If the Sun were the size of a basketball, Earth would be a little dot no more than 2.2mm in diameter

What is a sunspot?

Signifying cooler areas, sunspots show up as dark dots on the photosphere (the visible layer of plasma across the Sun's surface). These 'cool' regions – about 1,000 degrees cooler than the surface temperature – are associated with strong magnetic fields. Criss-crossing magnetic-field lines can disturb the flow of heat from the core, creating pockets of intense activity. The build up of heat around a sunspot can be released as a solar flare or coronal mass ejection, which is separate to but often accompanies larger flares. Plasma from a CME ejects from the Sun at over 1 million miles per hour.

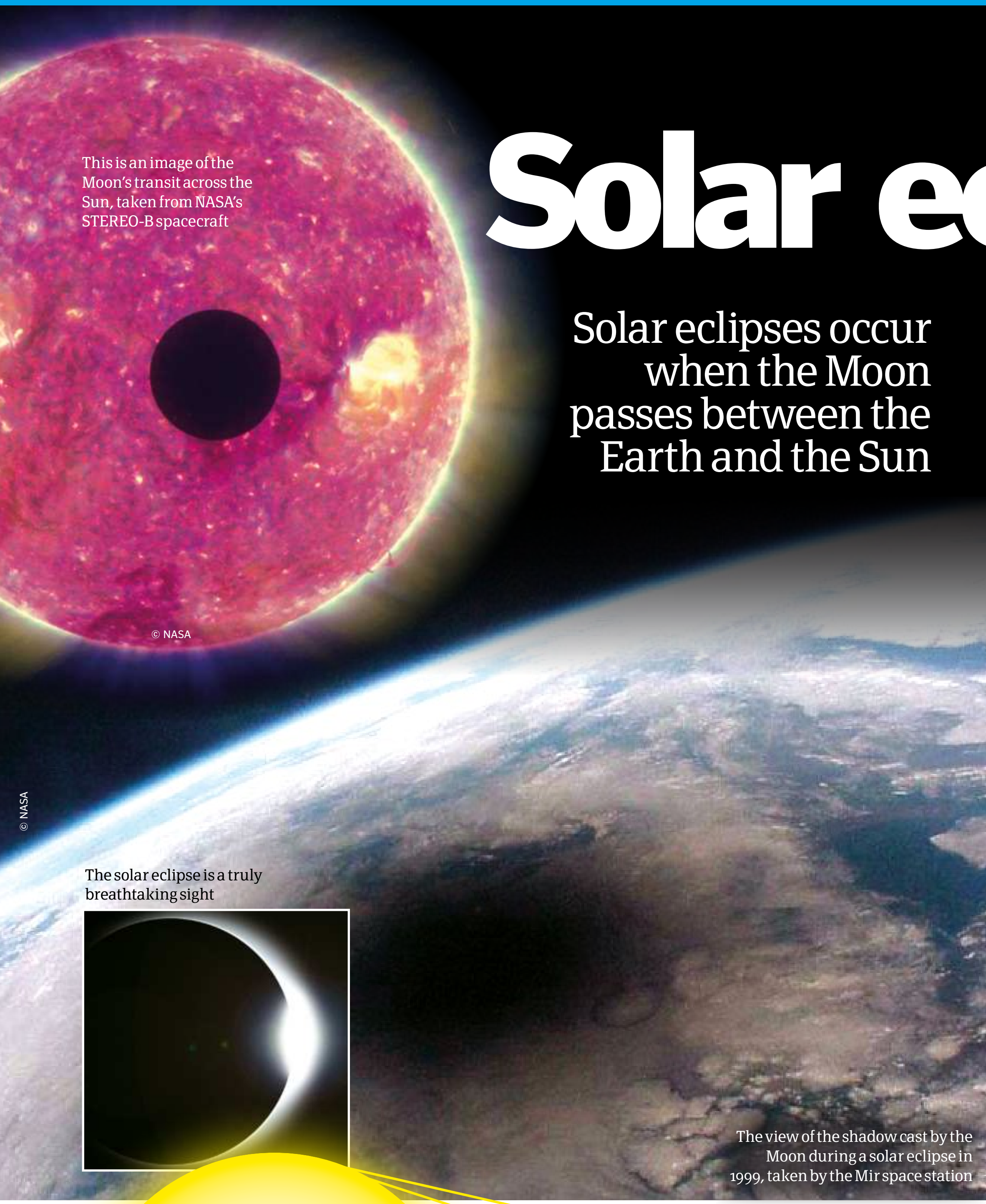


It's the Sun, but not as we know it

These amazing images of the Sun are the first taken by NASA's Solar Dynamics Observatory (SDO). Taken on 30 March 2010, this false colour image traces the different gas temperatures with reds relatively cool (about 60,000 Kelvin or 107,540 F), while blues and greens are hotter (1 million Kelvin or 1,799,540 F). The SDO provides images with clarity ten times better than high-definition TV.

Solar eclipse

Solar eclipses occur when the Moon passes between the Earth and the Sun



This is an image of the Moon's transit across the Sun, taken from NASA's STEREO-B spacecraft

© NASA

The view of the shadow cast by the Moon during a solar eclipse in 1999, taken by the Mir space station

© NASA

The solar eclipse is a truly breathtaking sight

During a solar eclipse, the Moon casts shadows on the Earth known as umbra or penumbra. The umbra is the darkest part of the shadow, while the penumbra is the area where part of the Moon is blocking the Sun. Partial eclipses happen when the Sun and Moon are not in perfect alignment – only the penumbra of the Moon's shadow passes over the surface of the Earth. In a total eclipse, the umbra touches the Earth's surface.

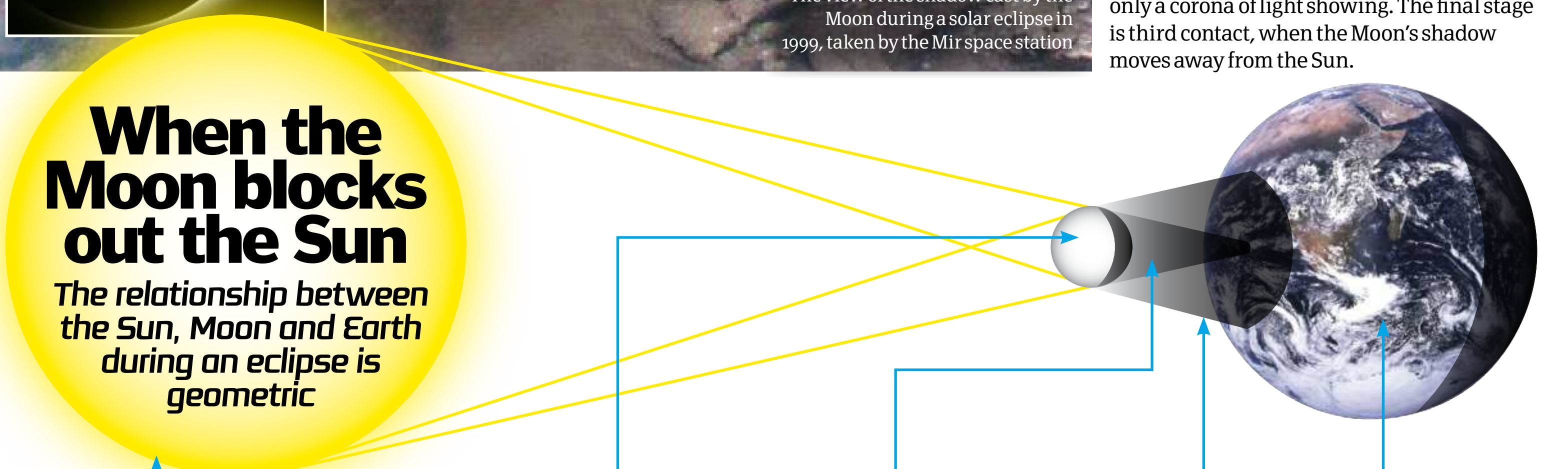
There are also annular eclipses, in which both the Sun and the Moon are in alignment but the Moon appears to be slightly smaller than the Sun. The Sun appears as a bright ring, or annulus, around the Moon's profile. The umbra is still in line with a region on the Earth's surface, but the distance is too great to actually touch the surface of the Earth.

Depending on your location, an eclipse may appear to be any of the three possible types. For example, if your region lies in the path of totality, you will experience a total eclipse, while people in other regions may only see a partial eclipse. Solar eclipses occur between two and five times per year, with most of these being partial or annual eclipses.

Total eclipses have four phases. First contact occurs when you first notice the shadow of the Moon on the Sun's surface. During second contact, you will observe a phenomenon called Baily's beads, when sunlight shines jaggedly through the rugged peaks and valleys of the Moon's surface. When one bead of light is left, it appears as a single dot in the ring, known as the diamond ring effect. Next, the Moon completely covers the Sun's surface with only a corona of light showing. The final stage is third contact, when the Moon's shadow moves away from the Sun.

When the Moon blocks out the Sun

The relationship between the Sun, Moon and Earth during an eclipse is geometric



1. Sun
The Sun and the Moon often appear to be the same size, because the ratio between their diameters is about the same as the ratio between their respective distances from Earth

2. Moon
The magnitude of an eclipse is the ratio between the angular diameters of the Moon and Sun. During a total eclipse this ratio is one or greater

3. Umbra
The umbra is the central area of the shadow of the Moon. If this area passes over you, you'll see a total eclipse. The sky will be completely dark

4. Penumbra
The penumbra is the outer part of the Moon's shadow. You will see a partial eclipse if this part passes over you and the sky will only be partially dark

5. Earth
In an annular solar eclipse, the umbra never touches the Earth because the Moon is too far away in its orbit. The Sun appears as a bright ring around the Moon's profile

All about the Moon

It took a walk on the Moon to reveal our natural satellite's many secrets

"One small step for a man, one giant leap for mankind", said the ghostly black-and-white shape of a man on live TV, broadcast to the whole world. This wasn't any ordinary man, though, and this wasn't an ordinary television broadcast, which had household upon household across the globe glued to their screens.

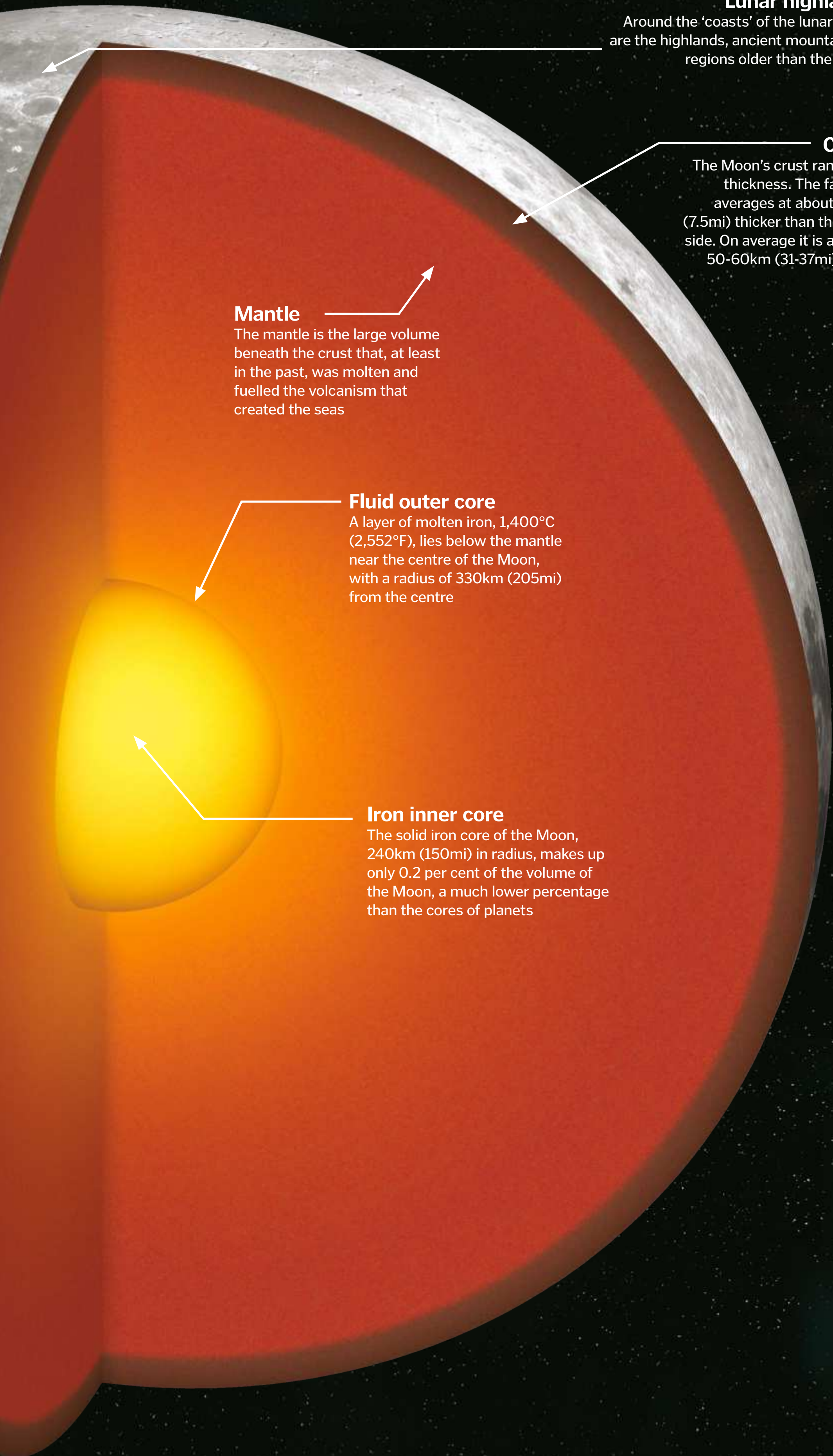
This was the summer of 1969 and Neil Armstrong had put spacesuit boot to soft, powdery lunar soil in a feat that had never been achieved before by anyone: he was the very first man to walk on the Moon. You might remember the Apollo 11 mission when it happened, or maybe you weren't even born, but you've managed to piece together what a momentous day it was for space exploration from newspaper cuttings, books or even from a story recounted by your relatives. Armstrong's bootprint signalled a historic change in how we see the Moon.

All throughout human history the Moon had been just a bright disc in the sky, its shape changing with a monthly regularity as different parts of it are illuminated by the Sun as it orbits Earth. Then, with the beginning of the Space Race between the USA and the Soviet Union, the Moon became a target to be reached, first by robotic probes and then by human beings. It transformed from a silvery disc into a real world, one that we have since come to understand better in part thanks to the astronauts who bravely travelled the 384,400 kilometres (238,855 miles) to its heavily cratered surface.

How craters are carved

Craters are the scars of impacts by comets and asteroids. Most of the craters on the Moon were formed during the Late Heavy Bombardment of 4.1-3.8 billion years ago, when an influx of asteroids invaded the inner Solar System. Craters can be dozens to hundreds of kilometres across, sport central peaks or mountains, and splash debris across the surface.

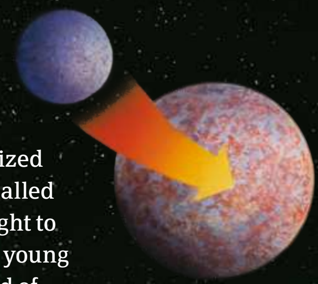
DID YOU KNOW? *There is no such thing as the 'dark side of the Moon' – both sides of the Moon get equal amounts of sunlight*



Making of the Moon

1 In for the kill

Around 4.4 billion years ago, a Mars-sized protoplanet called Theia is thought to have struck a young Earth at speed of 4km/s (2.5mi/s).



2 A planetary mix-up

The collision happened with such force that Theia's iron core sunk into the Earth, while the mantles of both planets mixed together.

3 The shape of things to come

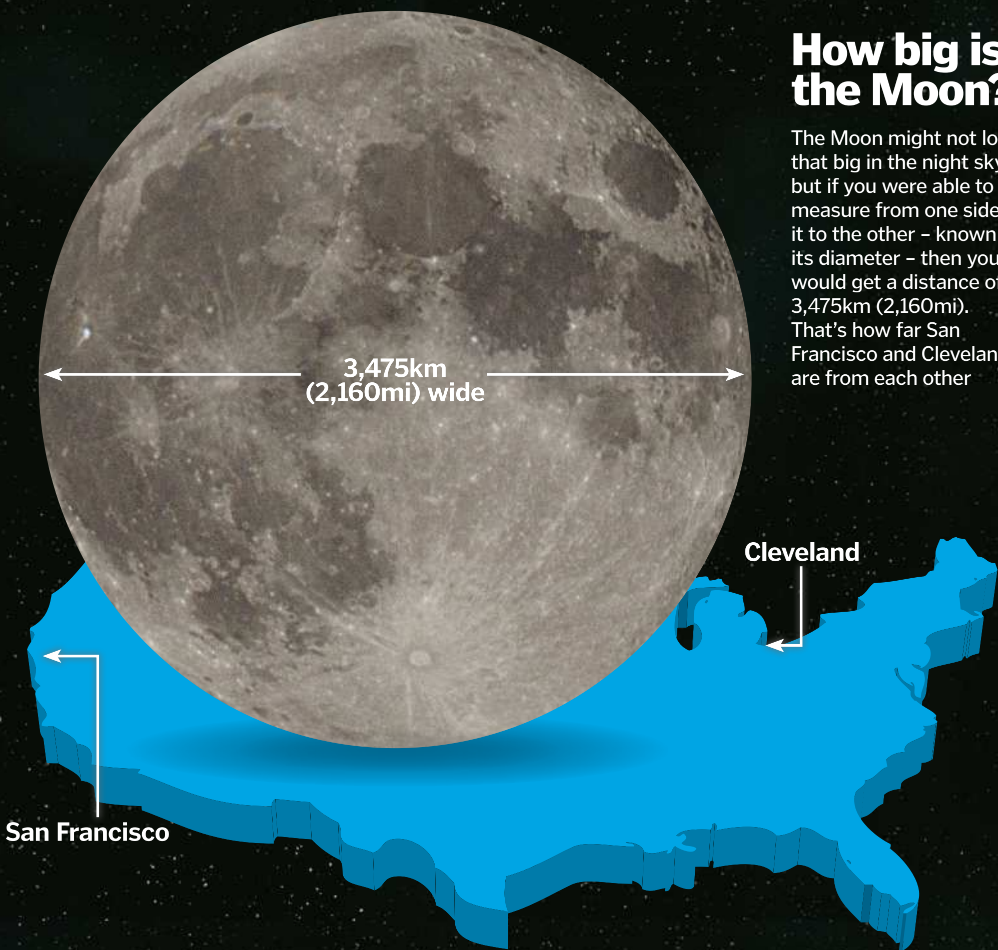
Not all of the planetary material mixed together, though – some of the mantle was tossed into orbit around Earth. These pieces would later combine to become our Moon.

4 A companion for life

Gravity rounded off the ejected material, leaving behind the bright natural satellite that we see in the sky.

Armstrong, who was Apollo 11's commander, wasn't alone on the lunar surface that day. Fellow astronaut and lunar module pilot Buzz Aldrin followed him down the ladder of their lunar lander, the Eagle, and took in the alien landscape of the Sea of Tranquility. Together, they collected samples of lunar material – dust and rocks – to bring back to Earth for scientists to study and learn more about the nature of the Moon, its history and its origins. Meanwhile, third crew member and command module pilot Michael Collins stayed in lunar orbit above them, waiting for Armstrong and Aldrin to return from the surface for the trip back to Earth.

They, and the other ten astronauts to walk on the Moon after them, left footprints in the lunar dirt that will remain on the Moon for probably as long as the Moon exists. The Moon is airless; there is no wind, no erosion other than the feather touch of tiny micrometeorites that pitter-patter the surface. Scientific instruments left behind on the Moon by the Apollo astronauts have detected the seismic waves of Moonquakes, but overall the Moon today is dead and inactive. Its most active period was three to four billion years ago, when the inner Solar System was bombarded by comets and asteroids. These impacts created most of the craters we see on the Moon, and this bombardment was followed by a period of intense volcanism on the Moon. The dark patches we can see on the Moon – the seas or 'maria' – are huge frozen plains of volcanic lava that filled the largest impact sites. It is the maria that contribute the pattern of facial features of the 'Man in the Moon.'



How big is the Moon?

The Moon might not look that big in the night sky, but if you were able to measure from one side of it to the other – known as its diameter – then you would get a distance of 3,475km (2,160mi). That's how far San Francisco and Cleveland are from each other

1,600 miles
The diameter of the Moon's largest crater

Harvest Moon
The Full Moon closest to the autumn equinox

12
The number of Moon walkers

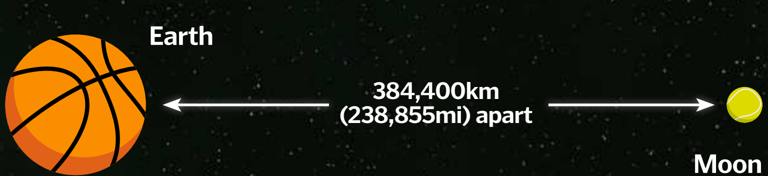
When there are two Full Moons in a month, we call the second one a...
Blue Moon

Percentage of the Moon visible from Earth
59%

382kg
Weight of all the rock samples returned by Apollo

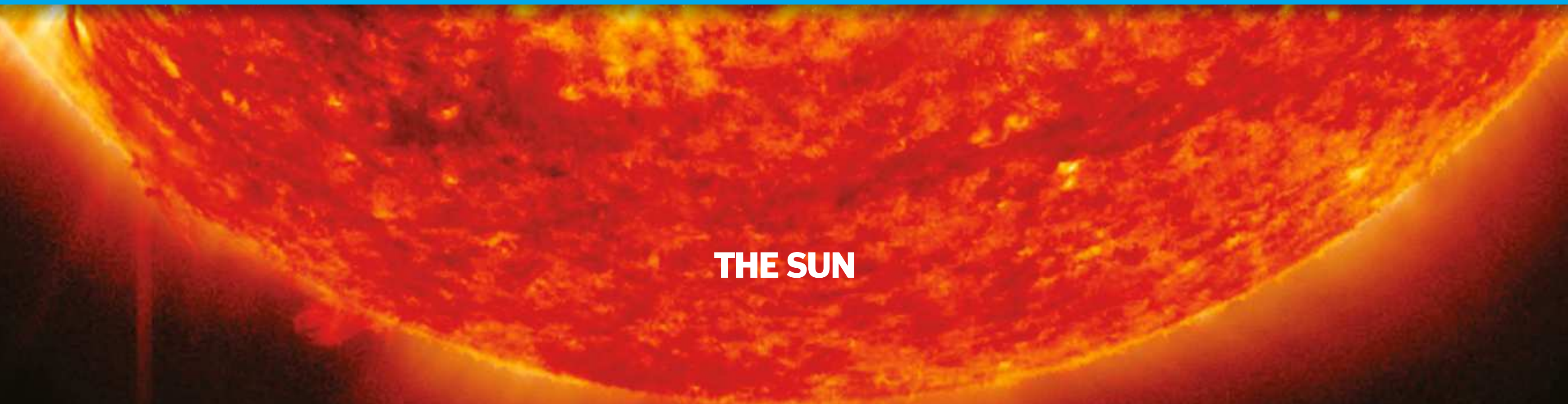
How far is the Moon?

Astronomically speaking, the Moon isn't that far away. An analogy would be if you used a basketball to represent the Earth and a tennis ball to represent the Moon, they would only be 7.3m (24ft) apart!



Gravity explained

Since it's lighter than Earth, our Moon's gravity is lower – that means you can jump higher on the lunar surface!



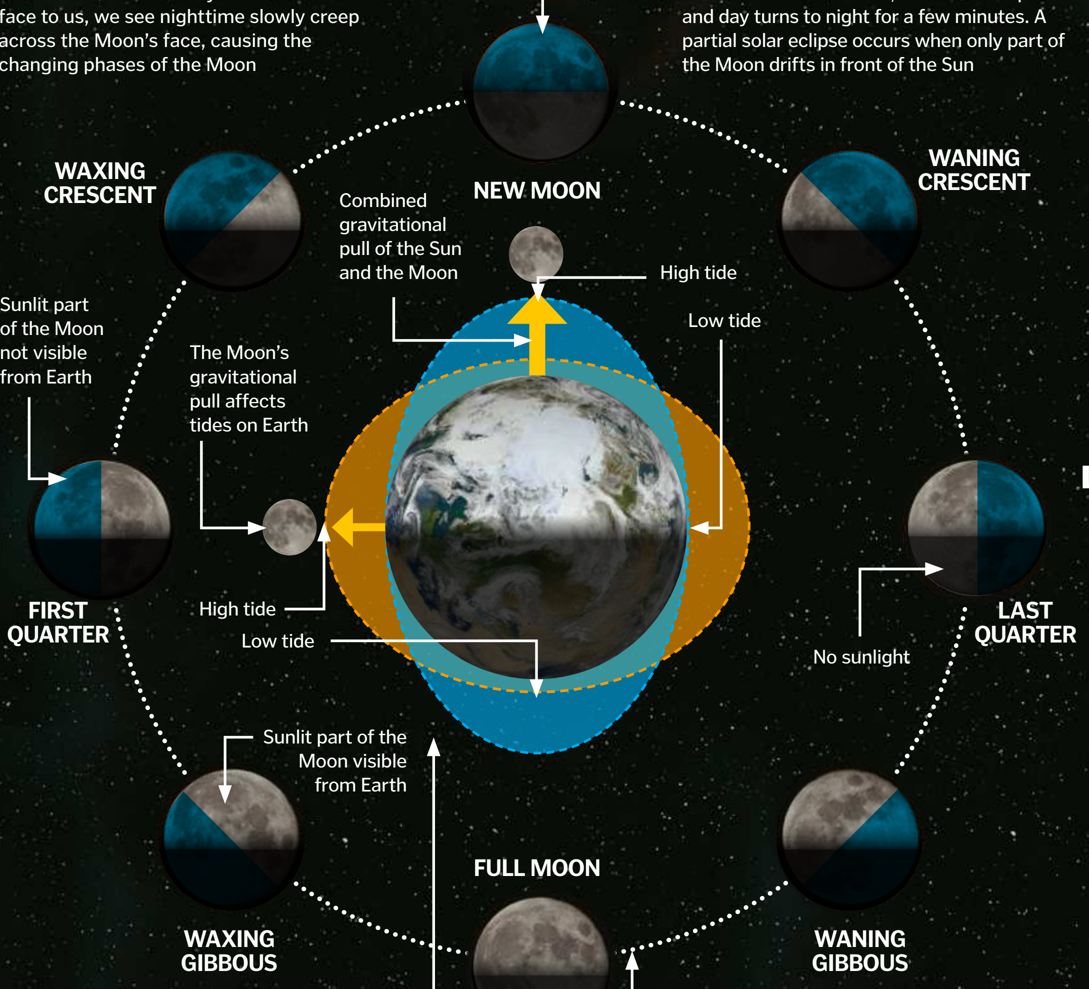
Phases of the Moon

Our companion in space, the Moon plays an important part in some interesting phenomena

New Moon
When the near side is completely in night time, with the far side in day time, we call it a New Moon

Phases
As the Moon pirouettes on its axis and dances around the Earth on its orbit, a lunar day lasts almost as long as an Earth month. Because the Moon always shows the same face to us, we see nighttime slowly creep across the Moon's face, causing the changing phases of the Moon

Eclipse
When the Moon moves into Earth's shadow, the Moon becomes eclipsed and turns dark, sometimes blood red. When Earth moves into the shadow of the Moon, the Sun is eclipsed and day turns to night for a few minutes. A partial solar eclipse occurs when only part of the Moon drifts in front of the Sun



Full Moon
When the near side is fully in daylight, we say the Moon is full

Tides
Ever wondered why the tide is in while at other times it's out? It's all to do with the gravity of the Moon as it moves around the Earth, as well as the Sun. Our lunar companion's gravity pulls the large bodies of water toward it, generating two tides per day

Orbit
Our natural satellite takes around 27.3 days to complete one lap around our planet, orbiting at a speed of around 1km/s (0.62mi/s). The Moon is at an average distance of around 385,000km (238,900mi) from the Earth's centre

Once upon a time, the lunar seas were thought to be seas of water by early astronomers. In reality the Moon is bone dry – the lunar rock samples brought back by the Apollo missions have been analysed over and over again and have been found to contain barely any water molecules at all, containing just a few parts per million. However, while there may not be much water inside the Moon – a result of the way the Moon formed from the debris of a giant impact on Earth – in deeply shadowed regions at the poles of the Moon, on crater floors where no sunlight ever reaches, large quantities of water-ice lurk. This ice has been brought to the Moon by comets and asteroids that have crashed into it, and we discovered this by crashing our own impactor into the lunar surface.

A NASA spacecraft, called LCROSS, the Lunar Crater Observation and Sensing Satellite, found water-ice inside a crater at the lunar south pole called Cabeus. The upper stage of the rocket that launched LCROSS crashed into the crater ahead of LCROSS, allowing the NASA probe to measure the amount of water in the debris plume from the impact. Then India's Chandrayaan-1 satellite, orbiting the Moon, discovered an estimated 600 million tons of water-ice in permanently shadowed craters at the lunar north pole. The poles would be ideal places to locate future human bases: the water could be used for drinking, but also broken apart into oxygen atoms for breathing and hydrogen for rocket fuel.

Unfortunately, there is no sign we'll be going back to the Moon soon. The last astronaut to walk on the Moon, Gene Cernan of Apollo 17, did so in 1972. Since then there have been many plans to return, but each time they have been cancelled. NASA are currently building the Space Launch System, featuring the most powerful rocket since the Saturn V took the Apollo mission to the Moon, which could feasibly one day return humans to our nearest neighbour. The Chinese are also showing an interest in making a flight to the Moon. Whenever we go back, it may be for good, and when we do, it will fully transform the Moon into a new home away from home.

Far side

This is the side of the Moon we can't see without taking a mission to the Moon. You might be surprised to learn that it looks different to the near side

18 per cent visibility

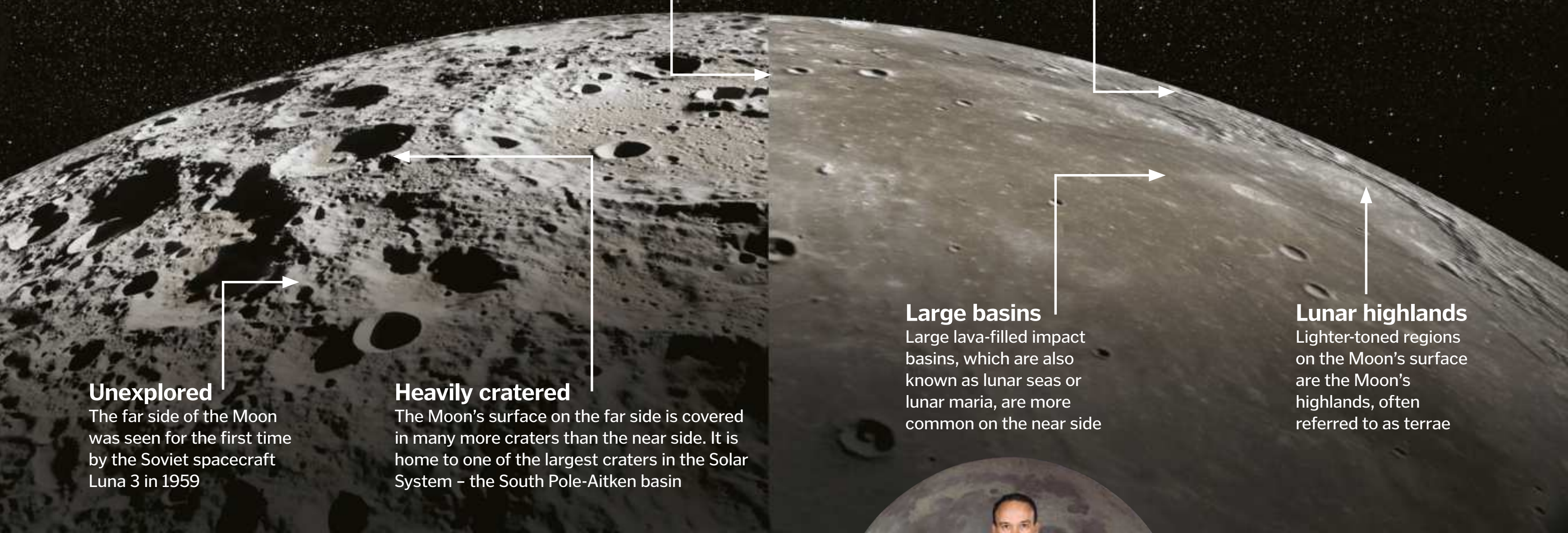
Since the Earth undergoes libration – in other words it oscillates in its orbit – then we catch a glimpse of 18 per cent of its far side

Thinner crust

The near side of the Moon has a thinner crust than the far side. The Moon's chaotic formation is thought to be responsible for this

Near side

The near side of the Moon is the face – or hemisphere – that we always see. This is because the Moon and Earth's spins are synchronised.



Large basins

Large lava-filled impact basins, which are also known as lunar seas or lunar maria, are more common on the near side

Lunar highlands

Lighter-toned regions on the Moon's surface are the Moon's highlands, often referred to as terrae

Unexplored

The far side of the Moon was seen for the first time by the Soviet spacecraft Luna 3 in 1959

Heavily cratered

The Moon's surface on the far side is covered in many more craters than the near side. It is home to one of the largest craters in the Solar System – the South Pole-Aitken basin

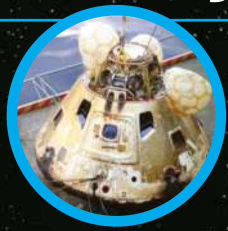
Moon exploration history

1959

The third space probe to be sent to the Moon, the Soviet spacecraft Luna 3, was an early attempt at imaging the far side of the Moon

1968

The second human spaceflight mission to the Moon, Apollo 8, became the first manned spacecraft to enter lunar orbit before safely returning to Earth



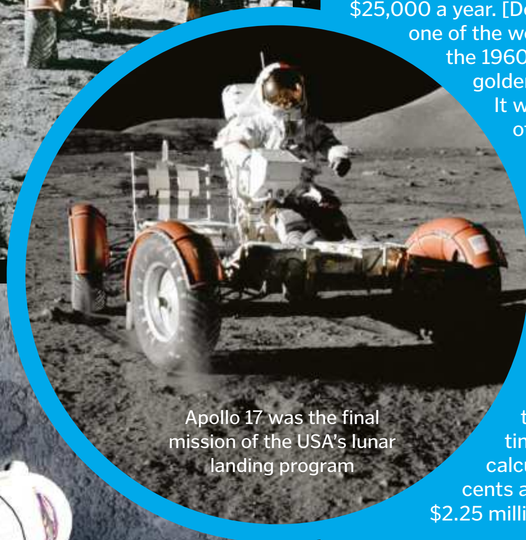
1969

Carrying Americans Neil Armstrong and Buzz Aldrin, Apollo 11 represented "one small step for a man, one giant leap for mankind" when they became the first to step onto the lunar surface. Astronaut Michael Collins piloted the command spacecraft in lunar orbit

1971

Dubbed as the most successful manned mission of its time, Apollo 15 was the first mission on which the Lunar Roving Vehicle was used. Its astronauts spent three days on the Moon

James Irwin of Apollo 15 salutes the US flag on 1 August 1971



Apollo 17 was the final mission of the USA's lunar landing program

The Lunar Crater Observation and Sensing Satellite (LCROSS) mission found water in the southern lunar crater Cabeus

Moon-walking

A chat with Walt Cunningham, Apollo 7's Lunar Module pilot

Why did you decide to become an astronaut?
(Laughs) I can tell you, it wasn't for the money! My starting salary when I went to work for NASA was $13,050 a year. When I left eight years later, I had worked my way up to $25,000 a year. [Despite the low pay] it was one of the world's greatest jobs and from the 1960s to the 1970s were the golden age of manned spaceflight. It was very much like the 1920s of aviation – we weren't flying planes with silk scarves and training out of a cockpit but you know, we felt like it.

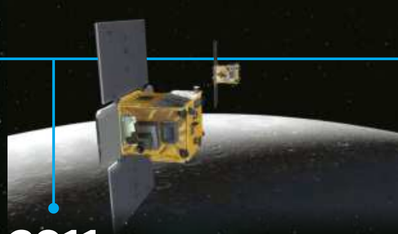
Why was your salary so low?
We weren't covered by NASA's flight insurance due to the high risk. If we had been, the rate would have been too high for all of the employees of NASA. One time, I did sit down and calculate that if I got paid 50 cents a mile, I would have made $2.25 million.

What does NASA look for when selecting their astronauts?
Individuals are hired on experience and qualifications but you must be willing to stick your neck out. We [commander Walter Schirra and Command Module pilot Donn Eisele] didn't shy away from the unknown and we were willing to take a risk. We depended on each other for our lives. Exploration isn't about eliminating risk, it's about managing risk. Future astronauts have the opportunity to accomplish much in the exploration of the Red Planet, Mars. We have the resources and the technology, but it's up to future generations to have the will to tackle this next frontier. This will expand our universe and change the way we all look at our world.

1972
Apollo 17 marked the end of the America's lunar landing program. Being a 'J-type mission', Apollo 17 included a three-day lunar surface stay and a Lunar Roving Vehicle

2008
India's first lunar probe, Chandrayaan-1, was comprised of a lunar orbiter and impactor. The impactor probe struck the south pole of the Moon

2009
The Lunar Reconnaissance Orbiter (LRO), which is currently in orbit around the Moon, maps the lunar surface to identify safe landing sites



2011
Made to crash into the Moon's surface when its mission came to an end in 2012, the Gravity Recovery and Interior Laboratory (GRAIL) was made of two probes that mapped the Moon's gravitational field

2013
China's Yutu rover, also called Jade Rabbit, marks the first soft landing on the Moon. While it's currently unable to move it is collecting useful data

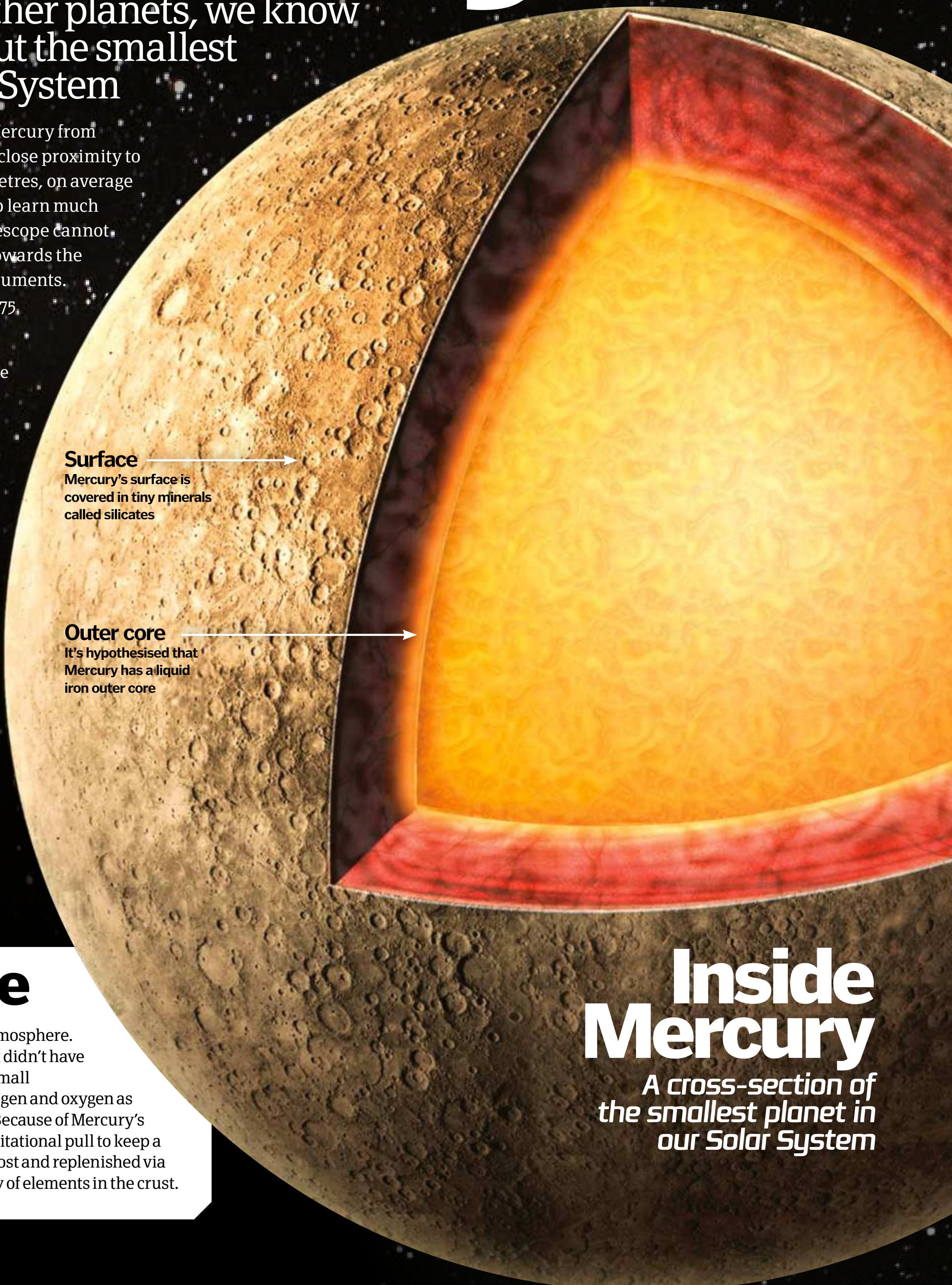
Mercury

Compared to the other planets, we know relatively little about the smallest planet in our Solar System

Although we've been observing Mercury from Earth for thousands of years, its close proximity to the Sun – about 58 million kilometres, on average – has made it difficult for astronomers to learn much about the planet. The Hubble Space Telescope cannot observe it, because turning that close towards the Sun would damage the telescope's instruments. Most of what we know came from the 1975 Mariner 10 space probe's fly-by.

With the naked eye, Mercury can only be seen at dawn or dusk, depending on the time of year (unless there is a solar eclipse). This is due to the Sun's glare. Mercury can also be seen as a small black spot moving across the Sun at intervals of seven, 13 and 33 years. This is known as a transit of Mercury across the Sun and occurs when the planet comes between the Earth and the Sun.

Mercury has the shortest year of any planet at 88 Earth days. It also orbits around the Sun faster than any other planet, which is why it was named after the speedy Roman messenger god. Conversely, Mercury has the longest day of any planet due to its slow rotation. Because it revolves so quickly around the Sun, yet only rotates on its axis once every 59 Earth days, the time between sunrises on Mercury lasts 176 Earth days. Mercury also has the most eccentric, or stretched-out, elliptical orbit. Like our moon, Mercury can be observed going through apparent changes in its shape and size called phases.



Inside Mercury

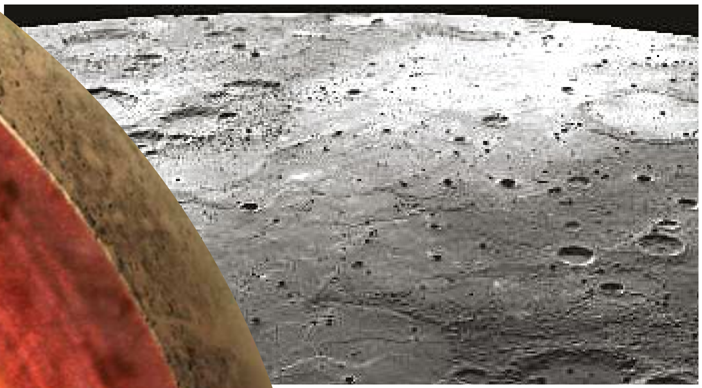
A cross-section of the smallest planet in our Solar System

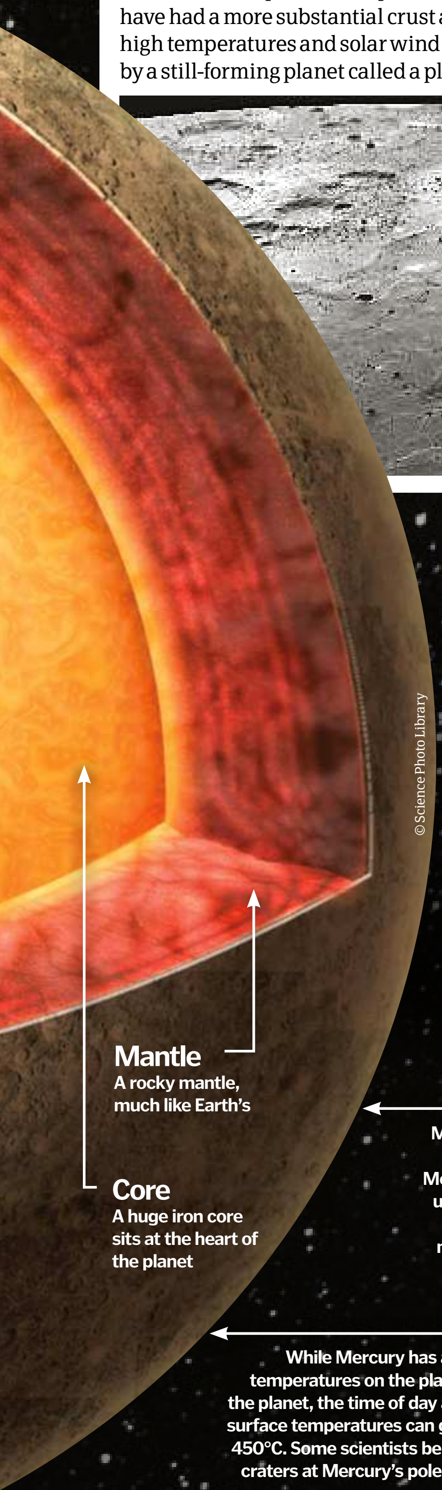
Atmosphere

Mercury has a very thin, almost airless atmosphere. At one time it was believed that the planet didn't have an atmosphere at all, but it does contain small concentrations of the gases helium, hydrogen and oxygen as well as calcium, potassium and sodium. Because of Mercury's size, it does not have a strong enough gravitational pull to keep a stable atmosphere. It is constantly being lost and replenished via solar wind, impacts and radioactive decay of elements in the crust.

Terrestrial planet

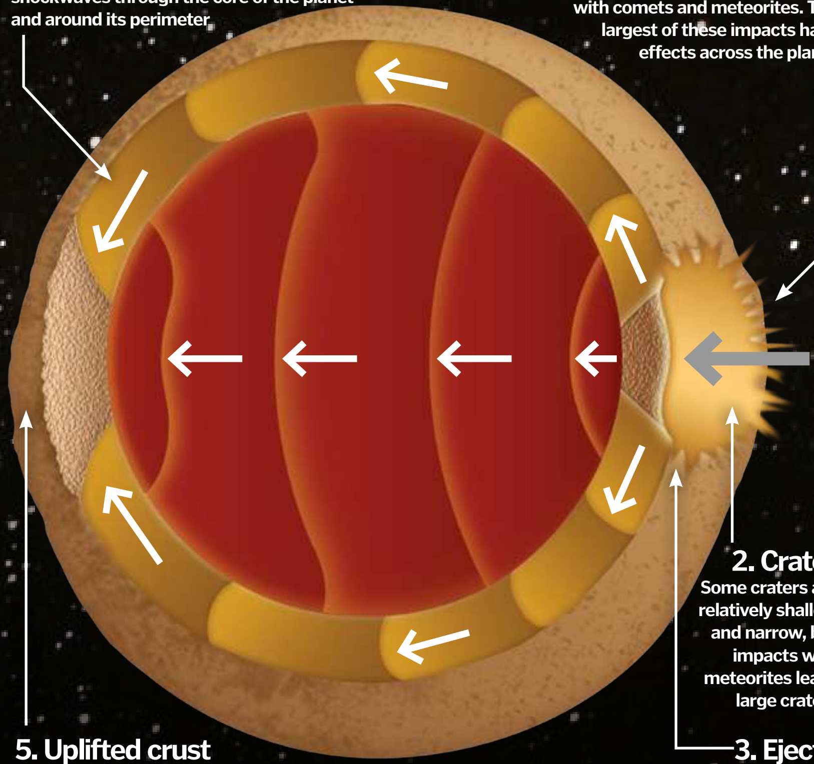
Like Earth, Mercury is a rocky planet. It comprises about 70 per cent metal and 30 per cent silicate materials. Because Mercury is so dense – almost as dense as Earth, although it's much smaller – it probably has a very large, iron-rich core. Scientists believe that Mercury's core makes up almost half of the planet's total volume and three-fourths of its total radius. It also contains more molten iron than any other major planet in the solar system. The core is estimated to have a radius of about 1,800 kilometres, with a mantle about 600 kilometres thick and a crust about 300 kilometres thick. There are a few potential explanations for this large core. Mercury may have had a more substantial crust and mantle that were stripped away by high temperatures and solar wind from the Sun, or it could have been hit by a still-forming planet called a planetesimal.





Moon-like surface

The surface of Mercury looks much like the surface of our moon. The largest crater on Mercury is the Caloris Basin at 1,300 kilometres across. The impact caused lava eruptions and shockwaves that formed hills and furrows around the basin. Mercury also has two different types of plains. The smooth plains were likely formed by lava flows, while inter-crater plains may have been formed by lava or by impacts. The most unusual features are the wrinkles and folds across its plains and craters, caused by the cooling and contraction of the planet's core.



The Statistics

Mercury

Diameter: 4,879km
Mass: 3.3022×10^{23} kg
Density: 5.427 grams per cubic centimetre
Average surface temperature: 179°C
Average distance from the Sun: 57,910,000km
Surface gravity: 0.38 g

Calori Montes

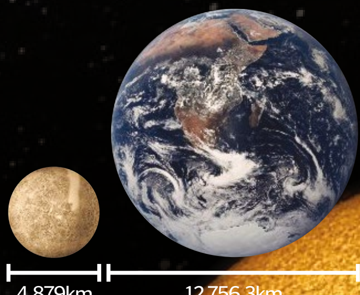
Mercury has several mountains known as montes, the tallest and largest of which are the Caloris Montes. This is a series of circular mountain ranges up to three kilometres in height located on the rim of the huge Caloris Basin. The Caloris Montes are massifs, formed when Mercury's crust flexed and fractured due to impact

Temperature extremes

While Mercury has an average surface temperature of around 179°C, temperatures on the planet fluctuate wildly depending on the location on the planet, the time of day and how close it is to the Sun in its orbit. At night, surface temperatures can go down to -170°C. During the day, they can reach 450°C. Some scientists believe that ice may exist under the surface of deep craters at Mercury's poles. Here temperatures are below average because sunlight cannot penetrate

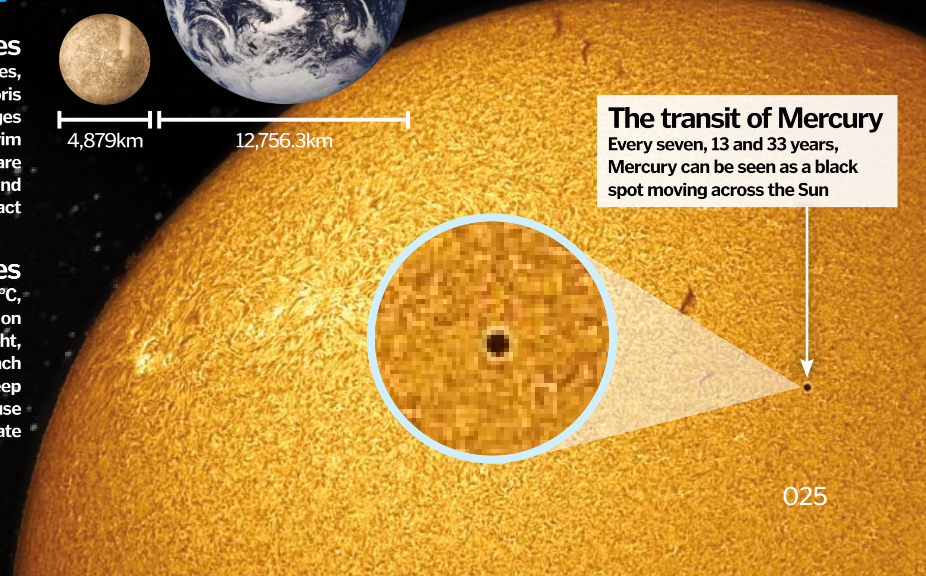
Sizes...

Mercury's diameter is two-fifths that of the Earth, and its mass is slightly less than Earth's



The transit of Mercury

Every seven, 13 and 33 years, Mercury can be seen as a black spot moving across the Sun



Venus

Discover just how similar this planet actually is to Earth…

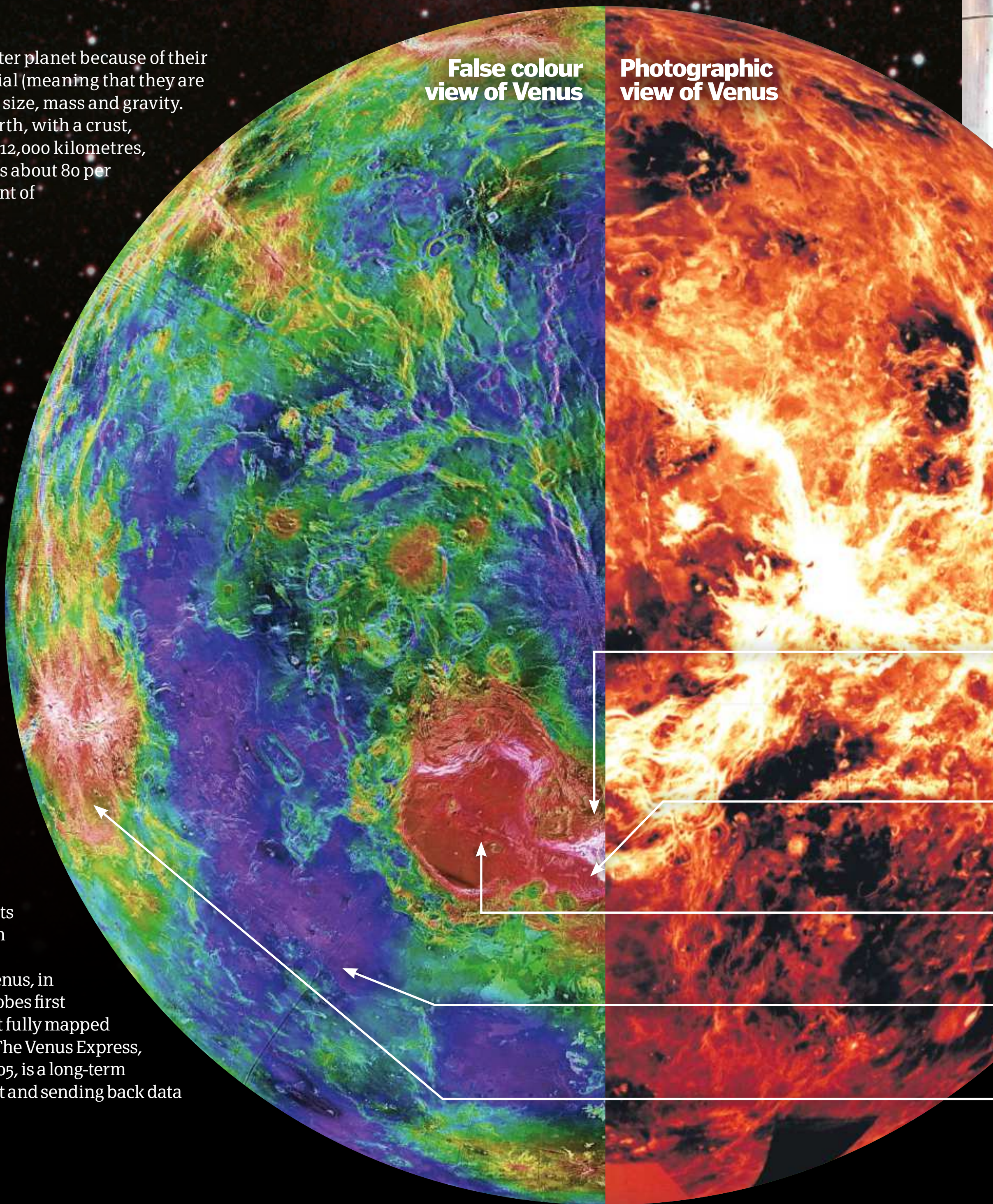
Venus has often been called Earth's sister planet because of their similarities. Both planets are terrestrial (meaning that they are made up of silicate rocks) and close in size, mass and gravity. Venus probably has a similar structure to Earth, with a crust, mantle and core. It has a diameter of around 12,000 kilometres, 650 kilometres smaller than Earth. Its mass is about 80 per cent of Earth's mass, and its gravity 90 per cent of Earth's gravity.

However, there are also many differences between Venus and Earth. Venus is about 108 million kilometres from the Sun and has an almost perfectly circular orbit, while all of the other planets have elliptical orbits. Venus completes one orbit every 225 days and has one of the slowest rotations of any planet, with one every 243 days. Venus's consistently high temperature means that it has no surface water.

The planet also has more than 1,500 volcanoes, many of which are more than 100 kilometres across. Most of the volcanoes are extinct, but some believe that there has been recent volcanic activity. Because Venus doesn't have rainfall, lightning could have been caused by ashy fallout from a volcanic eruption. These eruptions have created a rocky, barren surface of plains, mountains and valleys.

Venus is also covered with more than 1,000 impact craters. While Earth and other planets also have craters, Venus' are unusual because most of them are in perfect condition. They haven't degraded from erosion or other impacts. Venus may have experienced a massive event as much as 500 million years ago that resurfaced the planet and changed its atmosphere completely. Now bodies entering its atmosphere either burn up or are slowed down enough to avoid making a crater.

It has proven difficult to learn more about Venus, in part due to its dense atmosphere. Although probes first visited the planet in the early Sixties, it was not fully mapped by radar until the 1989 NASA Magellan probe. The Venus Express, launched by the European Space Agency in 2005, is a long-term exploration probe currently orbiting the planet and sending back data about its atmosphere.



The NASA Magellan spacecraft

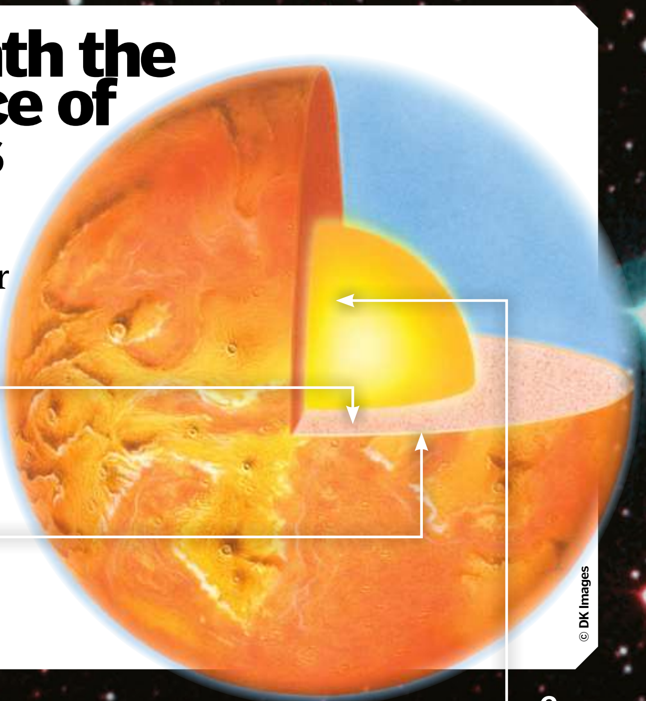
Venus' atmosphere

Immense pressure of the atmosphere

Venus's atmospheric pressure is greater than that of any other planet – more than 90 times that of Earth's. This pressure is equivalent to being almost one kilometre below the surface of Earth's oceans. The atmosphere is also very dense and mostly carbon dioxide, with tiny amounts of water vapour and nitrogen. It has lots of sulphur dioxide on the surface. This creates a Greenhouse Effect and makes Venus the hottest planet in the solar system. Its surface temperature is 461 degrees Celsius across the entire planet, while Mercury (the closest planet to the Sun) heats up to 426 Celsius only on the side facing the Sun.

Beneath the surface of Venus

What lies at the core of Earth's sister planet?



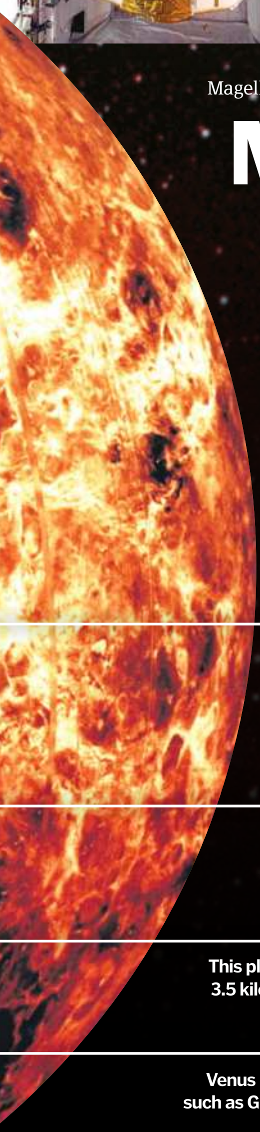
Mantle
Venus's mantle is probably about 3,000 kilometres thick and made of silicate rock

Crust
Venus likely has a highly basaltic, rocky crust about 100 kilometres thick

© DK Images

Core
Scientists believe that Venus's core is a nickel-iron alloy and partially liquid, with a diameter of 6,000 kilometres

Mapping Venus



Red indicates highland areas and blue indicates lower elevations in the false-colour view of Venus

1. Ishtar Terra
One of two 'continents', or major highland areas, on Venus, Ishtar Terra is located at the planet's North Pole. It is a little smaller than the continental United States

2. Maxwell Montes
Located on the north edge of Ishtar Terra, Maxwell Montes is the largest mountain range on Venus at nearly 11 kilometres high

3. Lakshmi Planum
This plateau in western Ishtar Terra rises about 3.5 kilometres above the surface of Venus. It is covered with lava flows

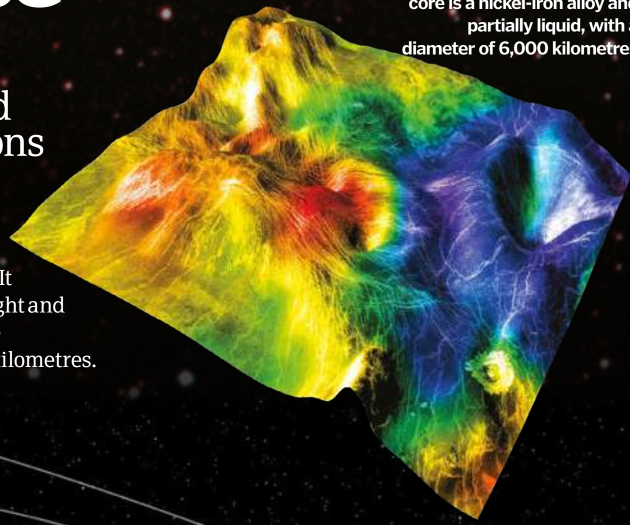
4. Guinevere Planitia
Venus is covered with regions of lowland plains such as Guinevere Planitia, which contains several volcanoes, impact craters and fissures

5. Beta Regio
Beta Regio is one of several volcanic rises on Venus' surface, more than 1,000 kilometres wide

The surface of Venus

Venus is covered in broad plains and elevated regions dotted by volcanoes

This computer-generated image shows a 7,500-kilometre-long region on the northern hemisphere of Venus known as Eistla Regio. It contains two volcanoes, Gula Mons on the right and Sif Mons on the left. Gula Mons is about three kilometres high and Sif Mons stands at two kilometres.

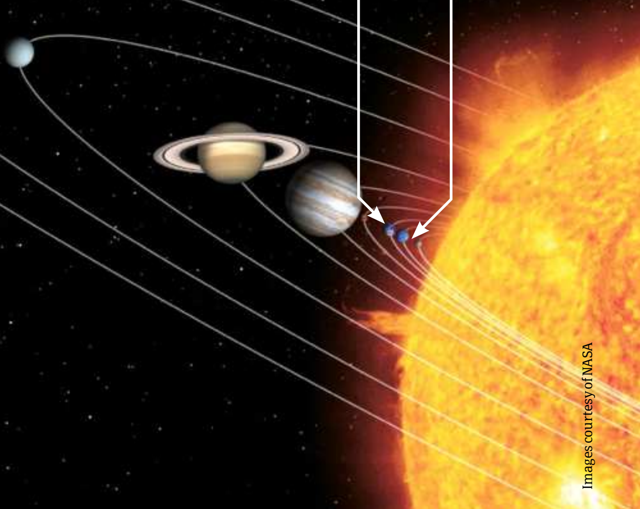


Sizes...

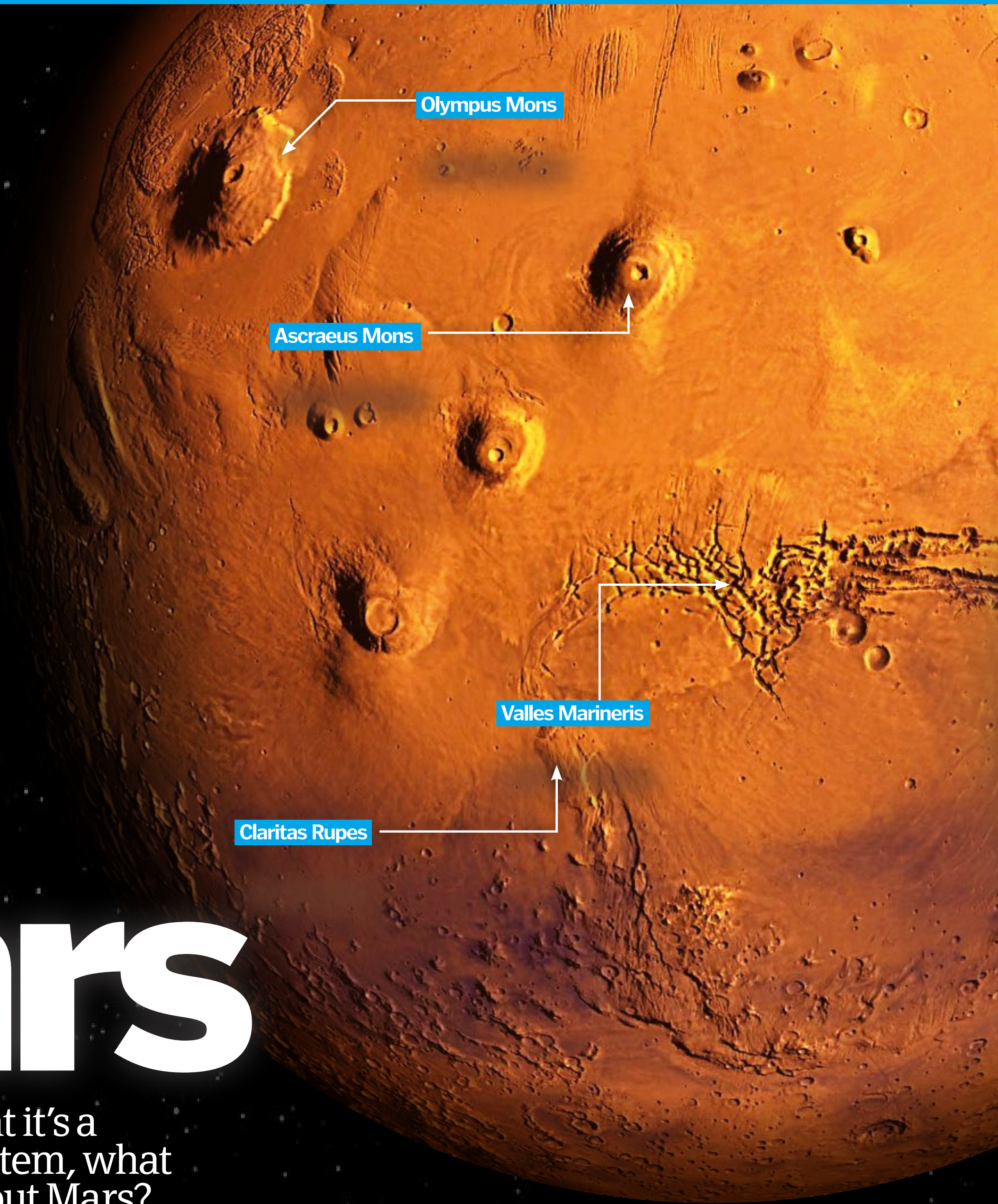
Venus and Earth are very similar in size. Venus's diameter is only 650km less than that of Earth, and the mass is 81.5 per cent of Earth's

12,103.6km

12,756.3km



Images courtesy of NASA



Mars

Other than the fact that it's a planet in our Solar System, what do we really know about Mars?

To date there have been almost 50 missions to Mars, with around half of those failing. Other than the Earth it is the most studied planet in the Solar System, and for centuries it has been at the heart of wild speculation and groundbreaking scientific discoveries. Observations of Mars have not only revealed otherwise unknown secrets but also posed new and exciting questions, and it is for these reasons that it has become the most intriguing planetary body of our time.

Named after the Roman god of war, Mars has fascinated astronomers since Nicolaus Copernicus first realised Mars was another planet orbiting the Sun in 1543. Its notable features such as huge impact craters, gullies and dormant volcanoes suggest it was once more geologically active than it is now, leading scientists to speculate on whether it supported water and life in the past, or indeed if it still does today. Astronomers in the 19th Century falsely believed they could see large oceans, and there were several reports of people receiving 'communications' from Martians in the form of bursts of light when they observed the planet through a telescope. Of course, we now have a better understanding of the planet, but we are still yet to unlock some of its most puzzling mysteries.

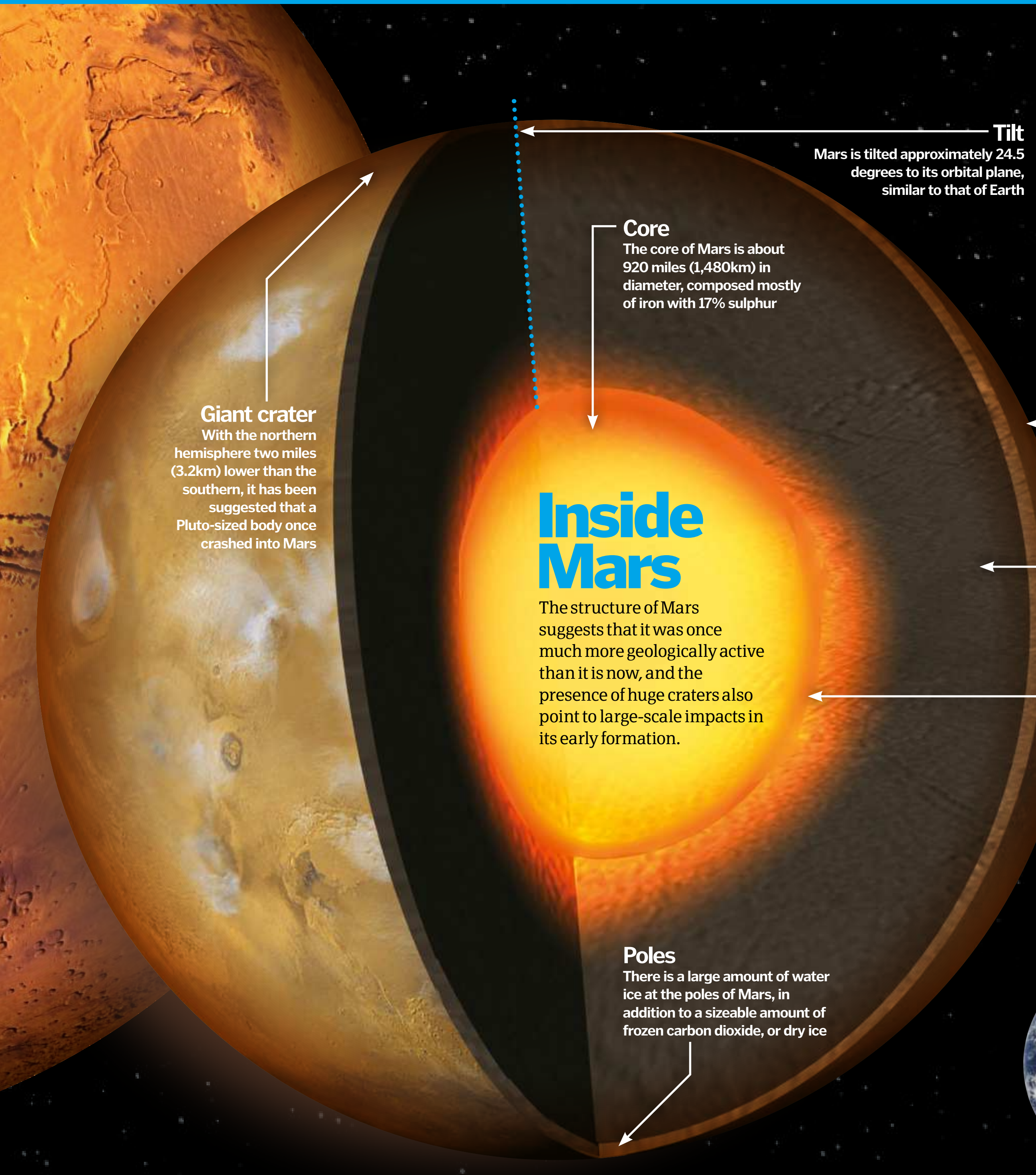
Mars sits 141 million miles (227 million km) from the Sun and takes 687 Earth days to orbit. As its orbital path is not in sync with Earth's it goes through a 26-month cycle of being closest (known as 'opposition') and furthest ('conjunction') from us, located at a distance of 35 million miles (56 million km) and 249 million miles (401 million km) respectively. This change in distance means spacecraft destined for Mars are sent in a launch window every 26 months, when Mars is closest to Earth. In November 2011, when NASA launched its new Mars rover, named 'Curiosity'. The journey time was upwards of six months, so Mars was actually closest on 3 March 2012.

Like all the planets in our Solar System, it is believed Mars formed about 4.5 billion years ago inside a solar nebula, when dust particles clumped together to form the planet. At just under half the size of Earth it's quite a small planet, which is accredited to Jupiter forming first. The gravitational forces of this gas giant consumed available material that would have otherwise contributed to Mars's growth, while Jupiter's gravity prevented another planet forming between Mars and Jupiter and instead left the asteroid belt. The northern hemisphere of Mars is significantly younger and lower in elevation than the southern hemisphere, suggesting the planet was struck by a Pluto-sized object early in its lifetime.

Mars is often referred to as something of a 'dead' planet. Indeed, its lack of folded

Inside Mars

The structure of Mars suggests that it was once much more geologically active than it is now, and the presence of huge craters also point to large-scale impacts in its early formation.




Sand dunes on Mars are constantly shifting

mountains like those on Earth show that it has no currently active plate tectonics, meaning carbon dioxide cannot be recycled into the atmosphere to create a greenhouse effect. For this reason Mars is unable to retain much heat, with a surface temperature as low as -133°C at the poles in the winter, rising to 27°C on the day side of the planet during the summer.

Despite this, the atmosphere of Mars offers conclusive evidence that it was once geographically active. The outer planets in the Solar System have atmospheres composed of predominantly hydrogen and helium, but that of Mars contains 95.3% carbon dioxide, 2.7% nitrogen and 1.6% argon, with minimal traces of oxygen and water. This strongly suggests that volcanoes once erupted across its surface and spewed out carbon dioxide, further evidenced by giant mountains such as Olympus Mons that appear to be dormant volcanoes.

It might not be geologically active, but Mars does play host to some extreme weather conditions, most notably the appearance of dust devils. These tornadoes, ten times larger than anything similar on Earth, can be several miles high and hundreds of metres wide, creating miniature lightning bolts as the dust and sand within become electrically charged. The wind inside one of these, though, is almost unnoticeable, as the atmospheric pressure on Mars is so low. Interestingly, one of the reasons for the long survival rate of NASA's Mars rovers is that these dust devils have been cleaning their solar panels, allowing them to absorb more sunlight.

Mars's gravity is about 38% that of Earth, with just 10% of the mass. The surface pressure is just over 100 times weaker than ours at sea level, meaning that a human standing on the surface would see their blood instantly boil. The red colour on Mars's surface is the result of rusting, due to iron present in the rocks and soil reacting with oxygen to produce an iron oxide.

In 1877 the American astronomer Asaph Hall, urged on by his wife, discovered that Mars had two moons orbiting so close that they were within the glare of the planet. They were named Phobos and Deimos, after the attendants of Ares in the Iliad. Interestingly, the moons are not spherical like most other moons; they are almost potato-shaped and only about ten miles wide at their longest axis, indicating that they are the fragments of the collision of larger objects near Mars billions of years ago. Phobos orbits Mars more than three times a day, while Deimos takes 30 hours. Phobos is gradually moving closer to Mars and will crash into the planet within 50 million years, a blink of an eye in astronomical terms. The moons have both been touted as a possible base, from which humans could observe and travel to Mars.

Jupiter

We take a look inside the most massive planet in our Solar System

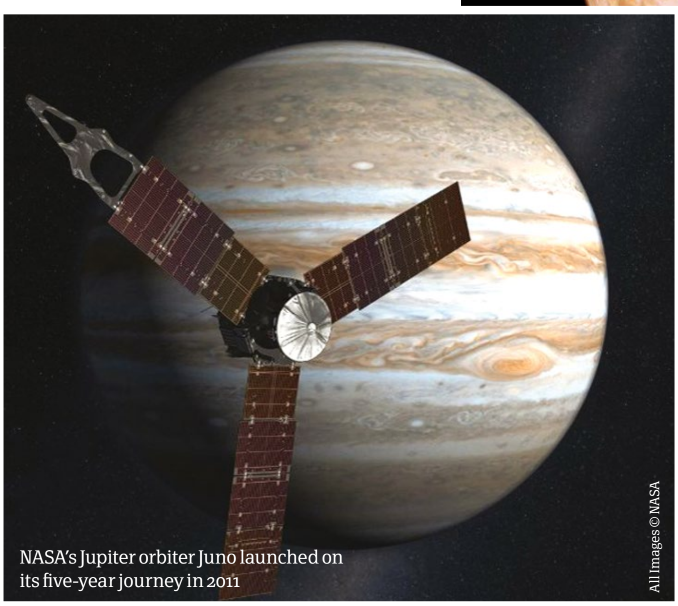
When Galileo Galilei discovered Jupiter in 1610, it is doubtful that he was aware of the impact this giant planet had on the surrounding Solar System. From altering the evolution of Mars to preventing the formation of a ninth planet, the size and mass of Jupiter has seen it exert an influence on its neighbours second only to the Sun.

Jupiter's mass and composition almost more closely resemble a star than a planet, and in fact if it was 80 times more massive it would be classified as the former. It can virtually be regarded as being the centre of its own miniature Solar System; 50 moons to date are known to orbit the gas giant, with the four largest (Io, Europa, Ganymede and Callisto, the Galilean satellites) each surpassing Pluto in size.

The comparison of Jupiter to a star owes a lot to the fact that it is composed almost entirely of gas. It has a large number of ammonia-based clouds floating above water vapour, with strong east-west winds in the upper atmosphere pulling these climate features into dark and light stripes. The majority of its atmosphere, however, is made up of hydrogen and helium.

The strength of Jupiter's gravity is such that it is held responsible for much of the development of nearby celestial bodies. The gravitational force of the gas giant is believed to have stunted the growth of Mars, consuming material that would have contributed to its size. It also prevented a new planet forming between these two and instead gave rise to the asteroid belt.

Much of our knowledge of Jupiter comes from seven spacecraft missions to visit the planet, starting with NASA's Pioneer 10 in 1973. The only man-made object to orbit the planet is the Galileo spacecraft, which studied the planet from 1995 until 2003, when it was sent crashing into Jupiter so as not to contaminate its moons with the debris.



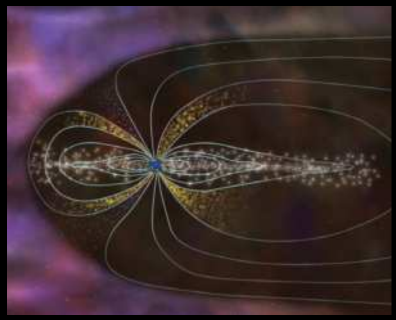
NASA's Jupiter orbiter Juno launched on its five-year journey in 2011

Jupiter's anatomy

Metallic hydrogen
A third of the way into the planet can be found hydrogen gas that has been compressed into a metallic and electrically conducting liquid

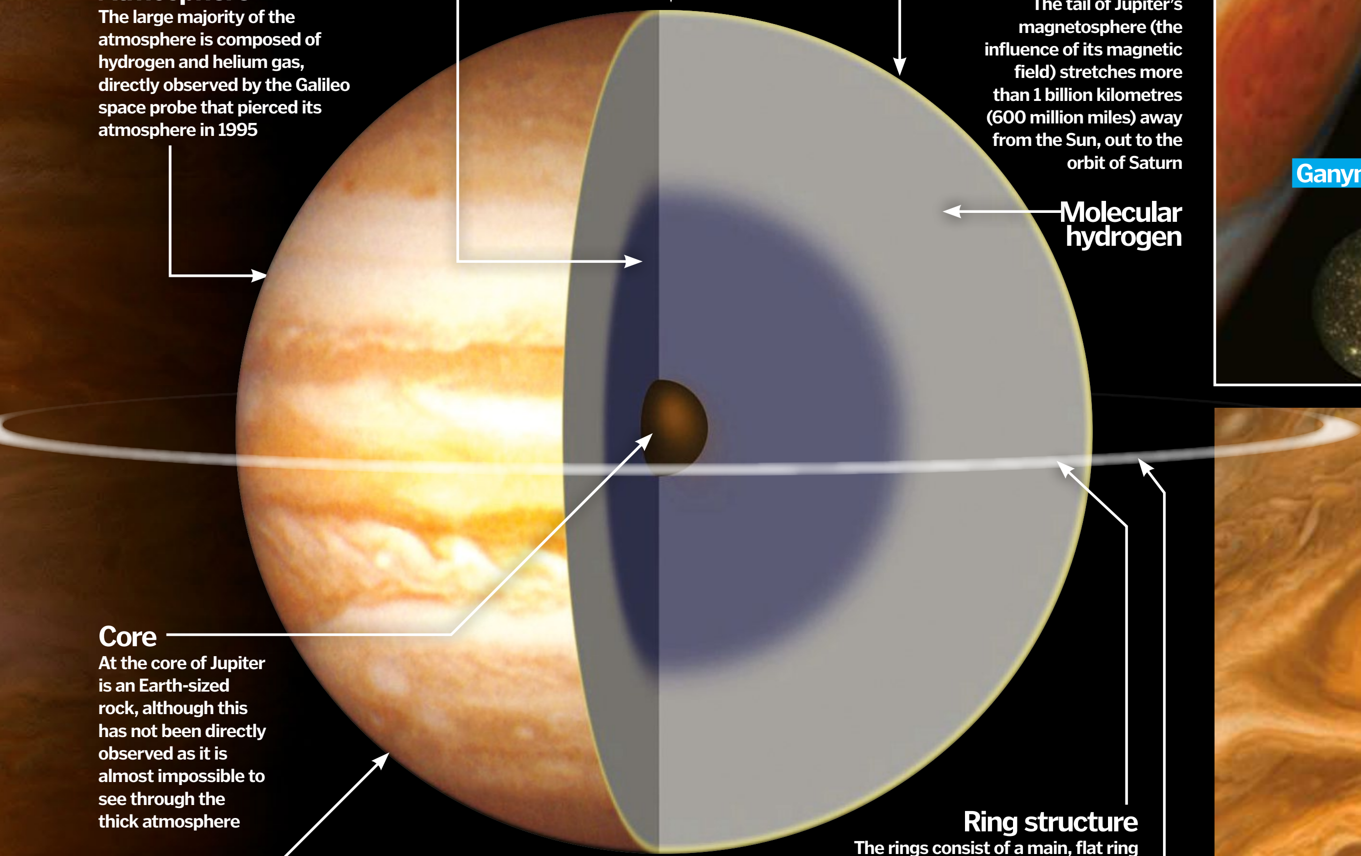
Atmosphere
The large majority of the atmosphere is composed of hydrogen and helium gas, directly observed by the Galileo space probe that pierced its atmosphere in 1995

Magnetic field
The magnetic field of Jupiter is 20,000 times stronger than Earth's, containing a huge number of charged particles that contribute to giant auroras at its north and south poles



Magnetosphere
The tail of Jupiter's magnetosphere (the influence of its magnetic field) stretches more than 1 billion kilometres (600 million miles) away from the Sun, out to the orbit of Saturn

Molecular hydrogen

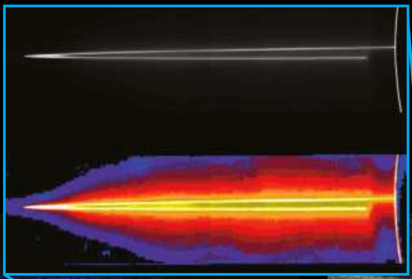


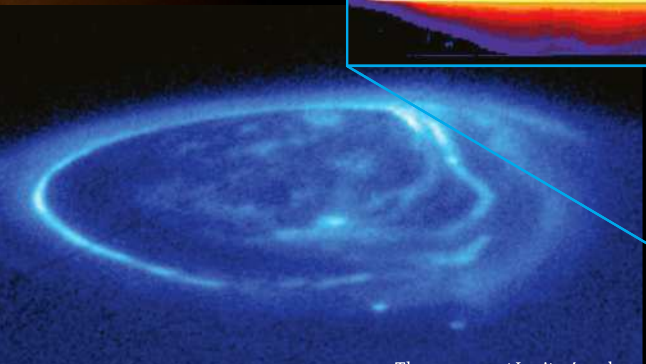
Core
At the core of Jupiter is an Earth-sized rock, although this has not been directly observed as it is almost impossible to see through the thick atmosphere

Aurora
An intense radiation belt of electrons and ions are trapped by Jupiter's magnetic field, influencing Jupiter's rings and its surrounding moons

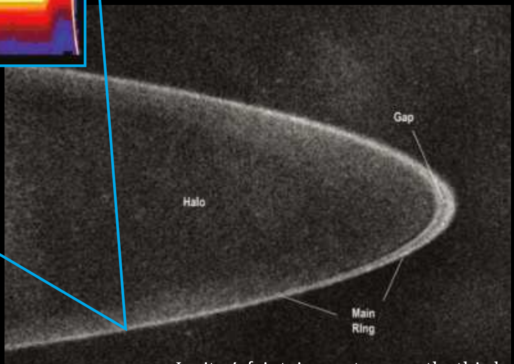
Ring structure
The rings consist of a main, flat ring and an inner cloud-like ring, known as a halo, with both made from small, dark particles kicked up by meteorites hitting Jupiter's moons

Rings
NASA's deep-space Voyager 1 spacecraft surprised astronomers in 1979 when it found rings encircling Jupiter. The rings are only visible in sunlight





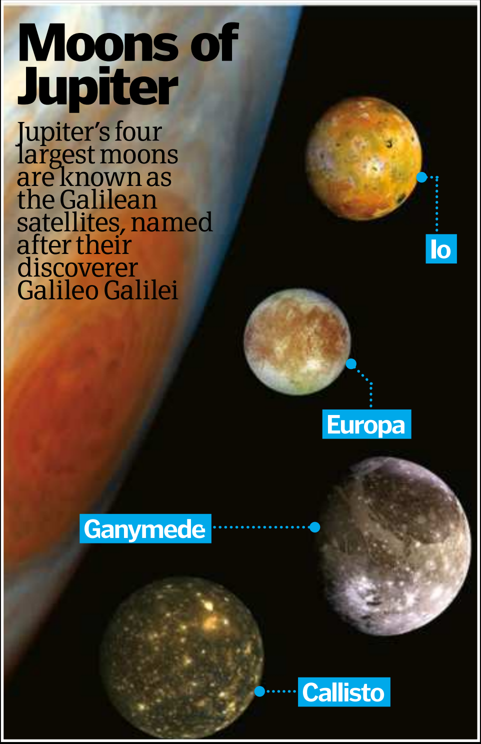
The auroras at Jupiter's poles are bigger than Earth

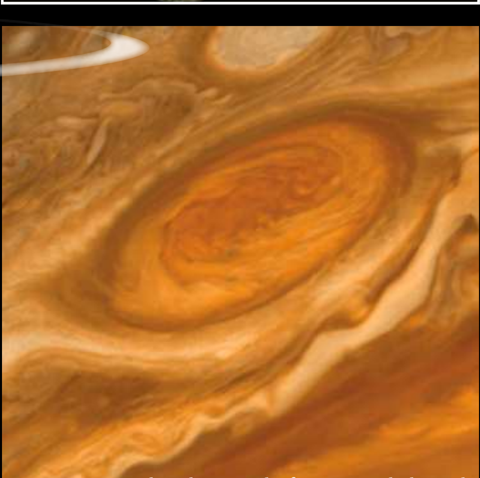


Jupiter's faint ring system was the third to be discovered in the Solar System

Moons of Jupiter

Jupiter's four largest moons are known as the Galilean satellites, named after their discoverer Galileo Galilei





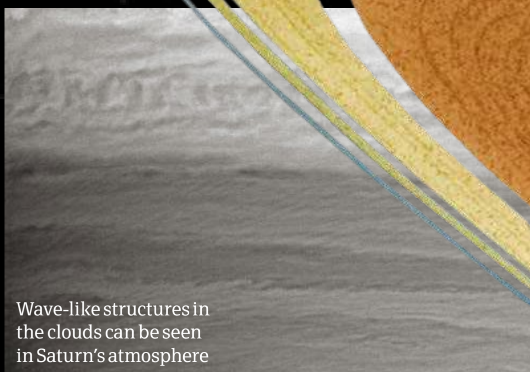
This photograph of Jupiter, with the Red Spot visible at the centre, was taken by NASA's Voyager 2 on 29 June 1979, as it flew past at a distance of almost 9 million kilometres (6 million miles)

The Great Red Spot

One of Jupiter's most iconic features is the Great Red Spot, a storm more than twice the size of Earth that has been raging for hundreds of years. The redness is believed to be the result of compounds being brought up from deeper inside Jupiter, which turn brown and red upon exposure to the Sun. Although once highly elliptical in shape, it has become squashed in recent years for unknown reasons and is expected to become circular other the next few decades, although this anti-cyclonic storm shows no sign of dying out any time soon.

Saturn

Only Jupiter is larger than this gas giant, best known for its ring system



Wave-like structures in the clouds can be seen in Saturn's atmosphere

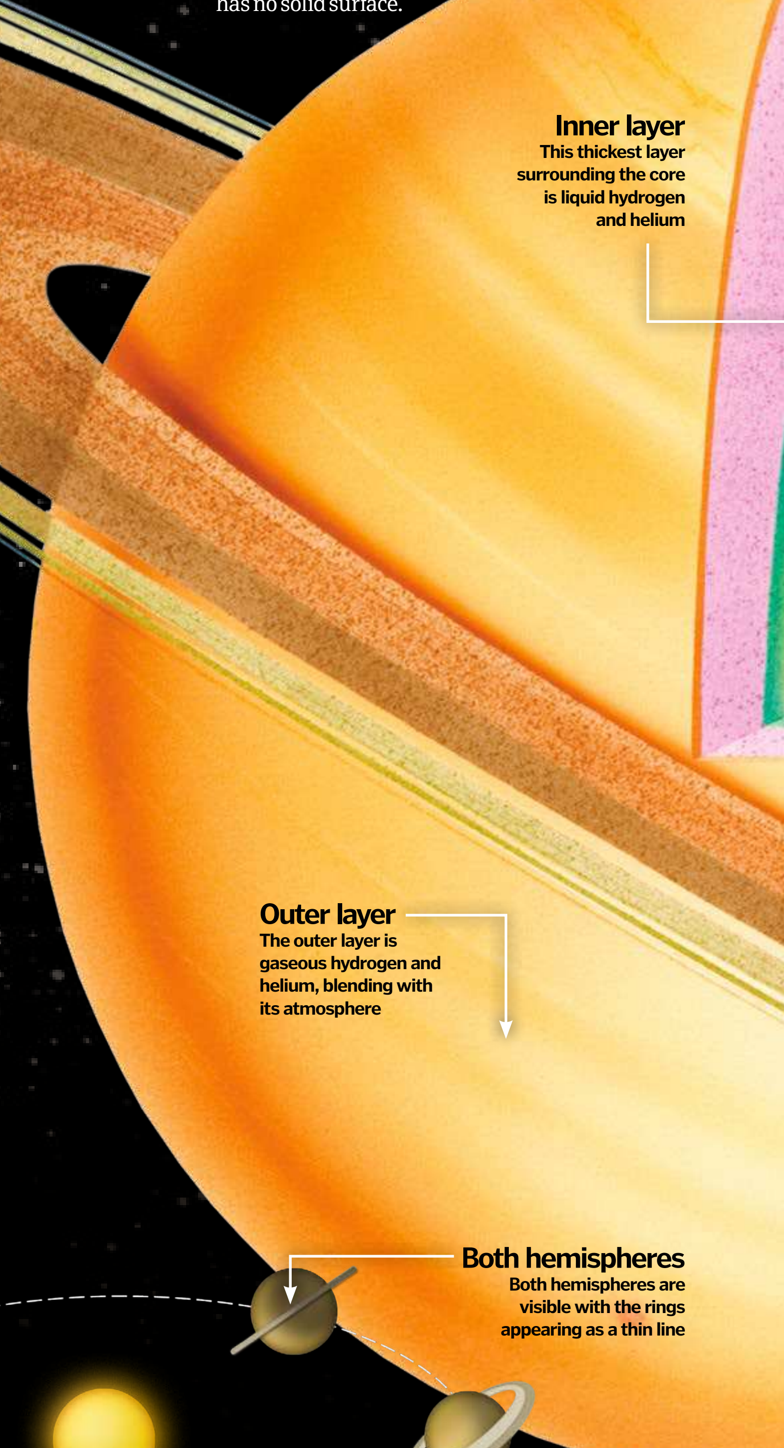
We've been viewing Saturn with the naked eye since prehistoric times, but the planet's most unique feature – its ring system – wasn't discovered until 1610. Each ring contains billions of chunks of dust and water-ice. Saturn has about 14 major ring divisions, but there are also satellites and other structures within some of the rings and gaps. Saturn's rings are believed to have come from the remains of moons, comets or other bodies that broke up in the planet's atmosphere.

The rings aren't the only fascinating thing about Saturn, however. This gas giant is less dense than any other planet in our solar system and has a mostly fluid structure. It radiates a massive amount of energy, thought to be the result of slow gravitational compression. Saturn takes about 29.5 years to revolve around the Sun, and its rotation is a bit more complex – different probes have estimated different times, the latest estimate is ten hours, 32 minutes and 35 seconds. The variations probably have something to do with irregularities in the planet's radio waves, due to the similarities between its magnetic axis and its rotational axis.

Saturn has a cold atmosphere comprising layered clouds of both water-ice and ammonia-ice. It also has winds of up to 1,800 kilometres per second. Occasionally Saturn has storms on its surface, similar to those of Jupiter. One such storm is the Great White Spot, a massive storm in the planet's northern hemisphere that has been observed about once every Saturnian year since 1876.

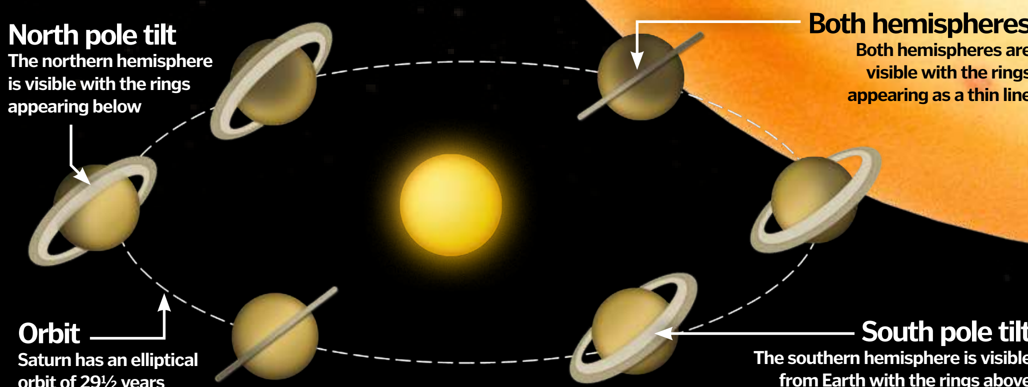
Inside Saturn

Saturn is believed to have a small rocky core, with a temperature of more than 11,000°C. It is surrounded by a layer of gases and water, followed by a metallic liquid hydrogen and a viscous layer of liquid helium and hydrogen. Near the surface, the hydrogen and helium become gaseous. Saturn has no solid surface.



Rings in view

Saturn takes 29.5 years to orbit the Sun, and it has an elliptical orbit like most planets. The closest Saturn comes to the Sun is 1.35 billion kilometres, while at its furthest, Saturn is 1.5 billion kilometres away. Saturn has a tilt of 26.7 degrees relative to the orbital plane. During half of its orbital period, the northern hemisphere is facing the Sun, while the southern hemisphere faces the Sun during the other half. When viewing Saturn from Earth, this impacts whether we can see the rings full-on or as a thin line.

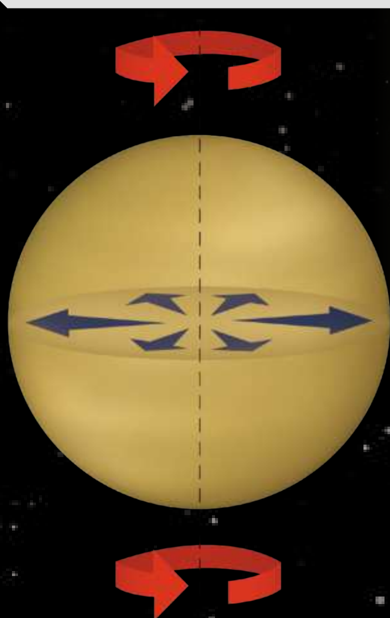


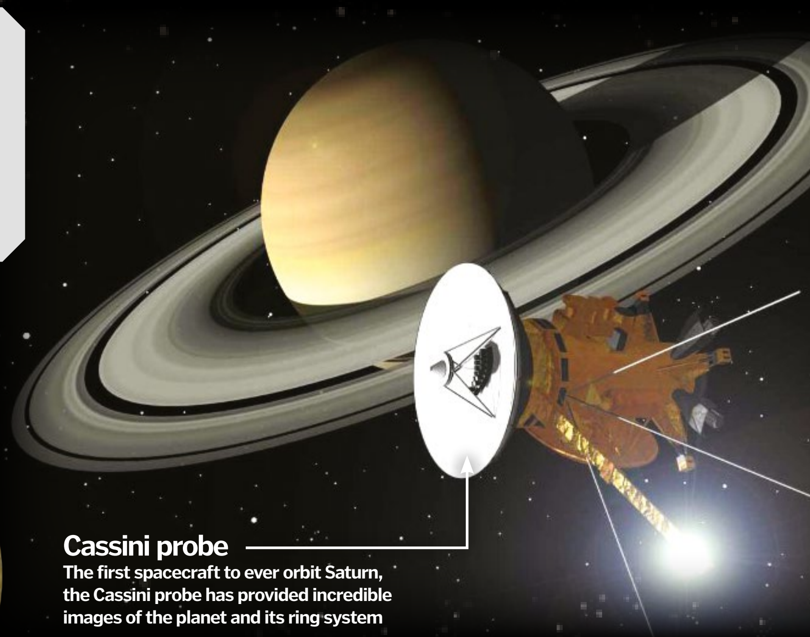
The Statistics
Saturn

Diameter: 120,535km
Mass: 5.6851 x 10^{26} kg
Density: 0.687 grams per cm^3
Average surface temperature: -139°C
Core temperature: 11,000°C
Moons: 62
Average distance from the Sun: 1,426,725,400km
Surface gravity: 10.44 metres per second squared

Extreme bulge

Saturn is an extreme example of an oblate spheroid – the difference between the radius of the planet at its poles and at its circumference is about ten per cent. This is due to its very short rotational period of just over ten hours.





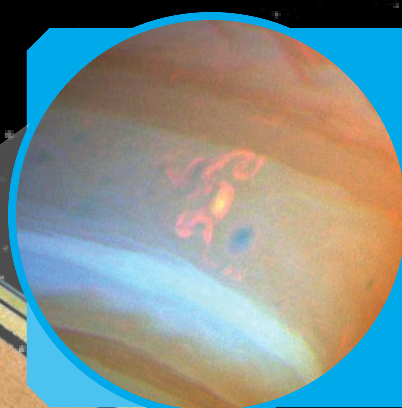
Cassini probe
The first spacecraft to ever orbit Saturn, the Cassini probe has provided incredible images of the planet and its ring system

Inner core
The inner core is likely very small and contains silicate rock, much like Jupiter's core

Float that planet

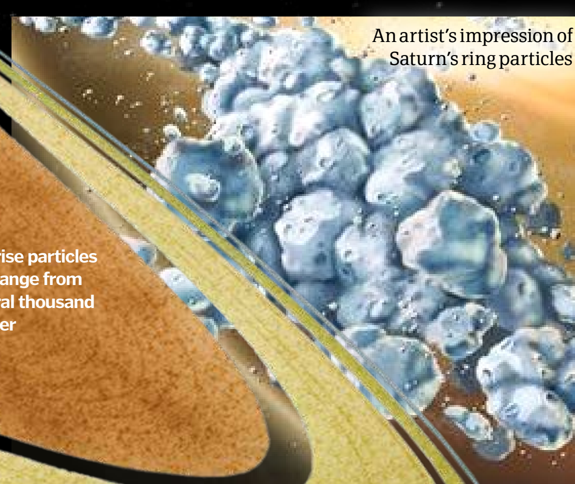
If we had a big enough pond, we could float Saturn on its surface. Although Saturn is the second-largest planet as well as the second-most massive, it's the least-dense planet in our solar system. Its density is just 0.687 grams per cubic centimetre, about one-tenth as dense as our planet and two-thirds as dense as water.

Outer core
Saturn's outer core is much thicker than its inner core, containing metallic liquid hydrogen



Saturn's southern storm

In 2004, the Cassini space probe discovered a massive, oddly shaped convective thunderstorm in Saturn's southern atmosphere. Dubbed the Dragon Storm, this weather feature emitted strong radio waves. Like storms on Earth, the Dragon Storm emits flashes of lightning that appear as white plumes. Scientists believe it exists deep in the atmosphere and can occasionally flare up.



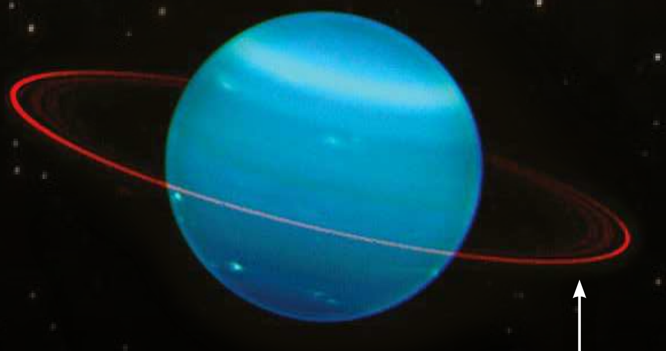
An artist's impression of Saturn's ring particles

Rings
Saturn's rings comprise particles of ice and dust that range from microscopic to several thousand kilometres in diameter

Uranus

The seventh planet from the Sun, third-largest and fourth most massive in the Solar System, Uranus was the first planet to be discovered by telescope

Capable of containing 63 Earths inside it (it is only 14.5 times as dense, as it is a gas giant), Uranus is the third largest in our Solar System. Appearing calm and pale blue when imaged, Uranus has a complex ring system and a total of 27 moons orbiting its gaseous, cloudy main body. Due to its distance from the Sun the temperature at the cloud-top layer of the planet drops to -214°C and because of its massive distance from Earth it appears incredibly dim when viewed, a factor that led to it not being recognised as a planet until 1781 by astronomer William Herschel.

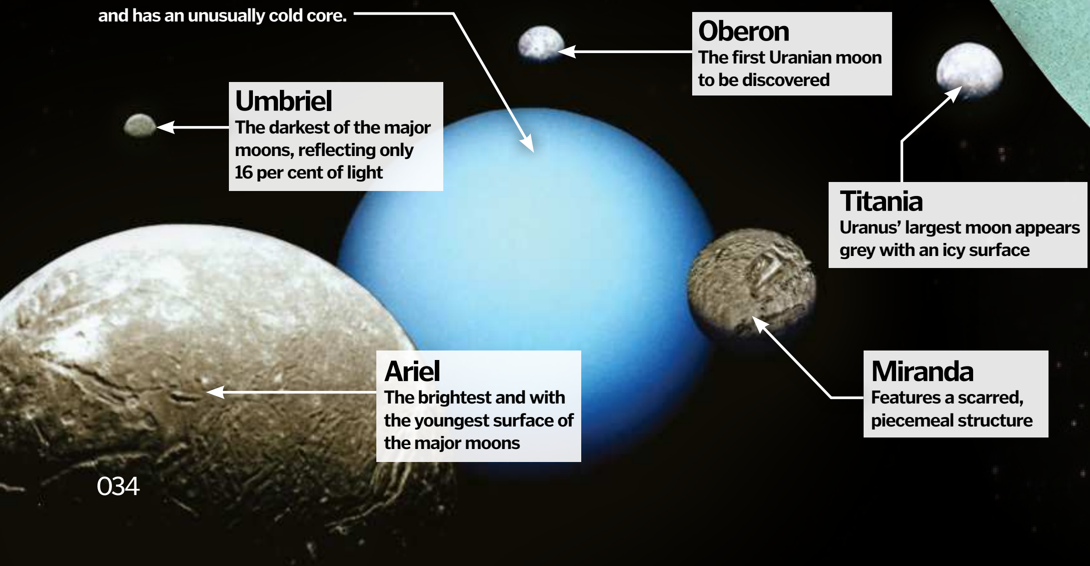


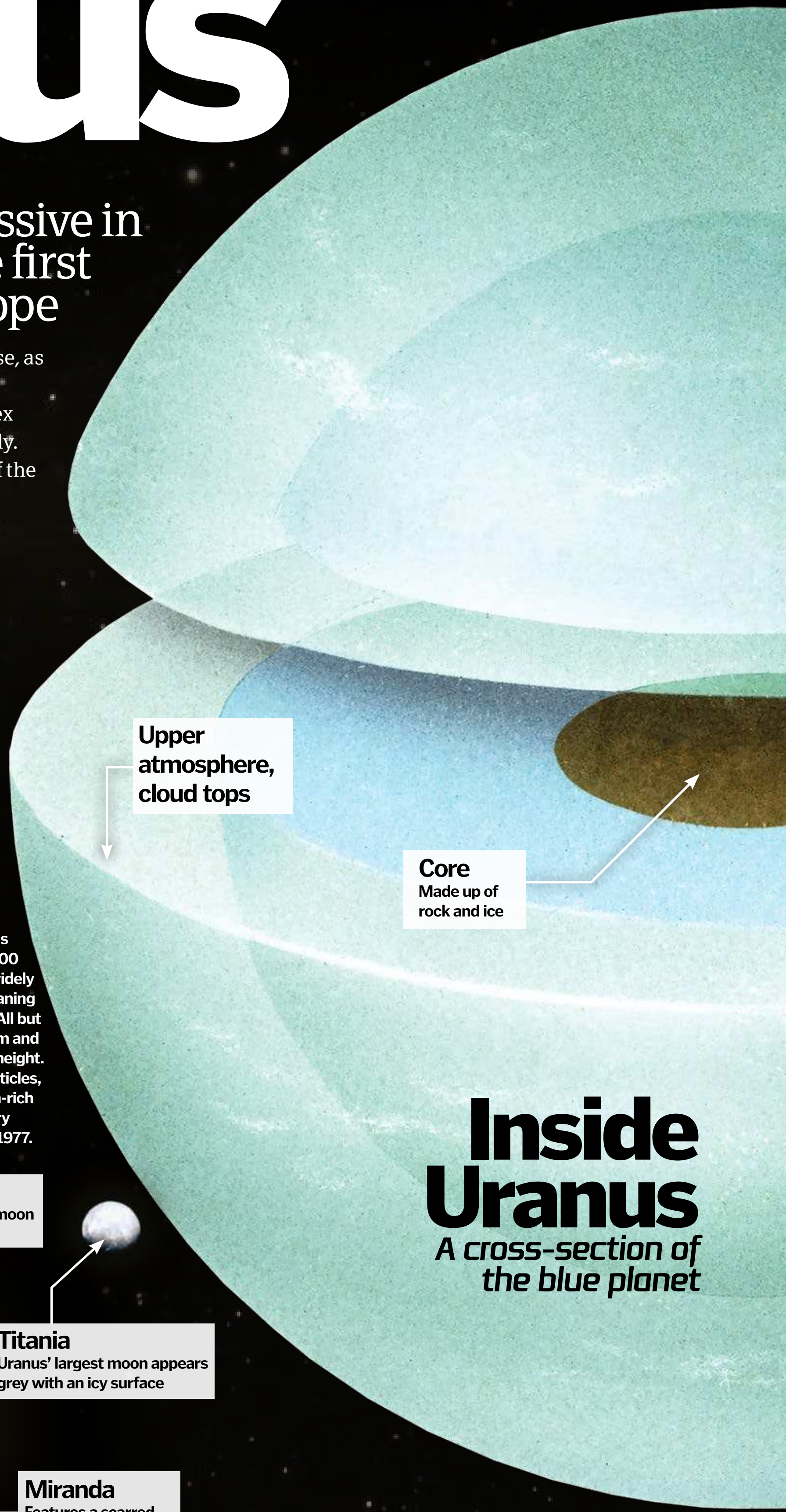
1. Atmosphere

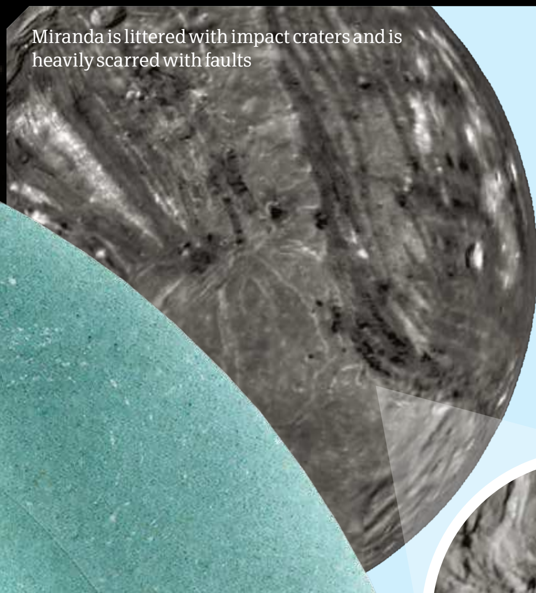
Uranus's blue colour is caused by the absorption of the incoming sunlight's red wavelengths by methane-ice clouds. The action of the ultraviolet sunlight on the methane produces haze particles, and these hide the lower atmosphere, giving the planet its calm appearance. However, beneath this calm façade the planet is constantly changing with huge ammonia and water clouds carried around the planet by its high winds (up to 560mph) and the planet's rotation. Uranus radiates what little heat it absorbs from the Sun and has an unusually cold core.

2. Rings

Uranus's 11 rings are tilted on their side, as viewed from Earth, and extend from 12,500 to 25,600km from the planet. They are widely separated and incredibly narrow too, meaning that the system has more gap than ring. All but the inner and outer rings are between 1km and 13km wide, and all are less than 15km in height. The rings consist of a mixture of dust particles, rocks and charcoal-dark pieces of carbon-rich material. The Kuiper Airborne Observatory discovered the first five of these rings in 1977.





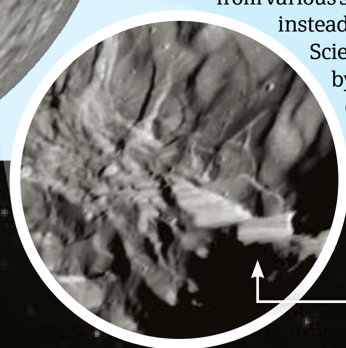


Miranda is littered with impact craters and is heavily scarred with faults

Miranda

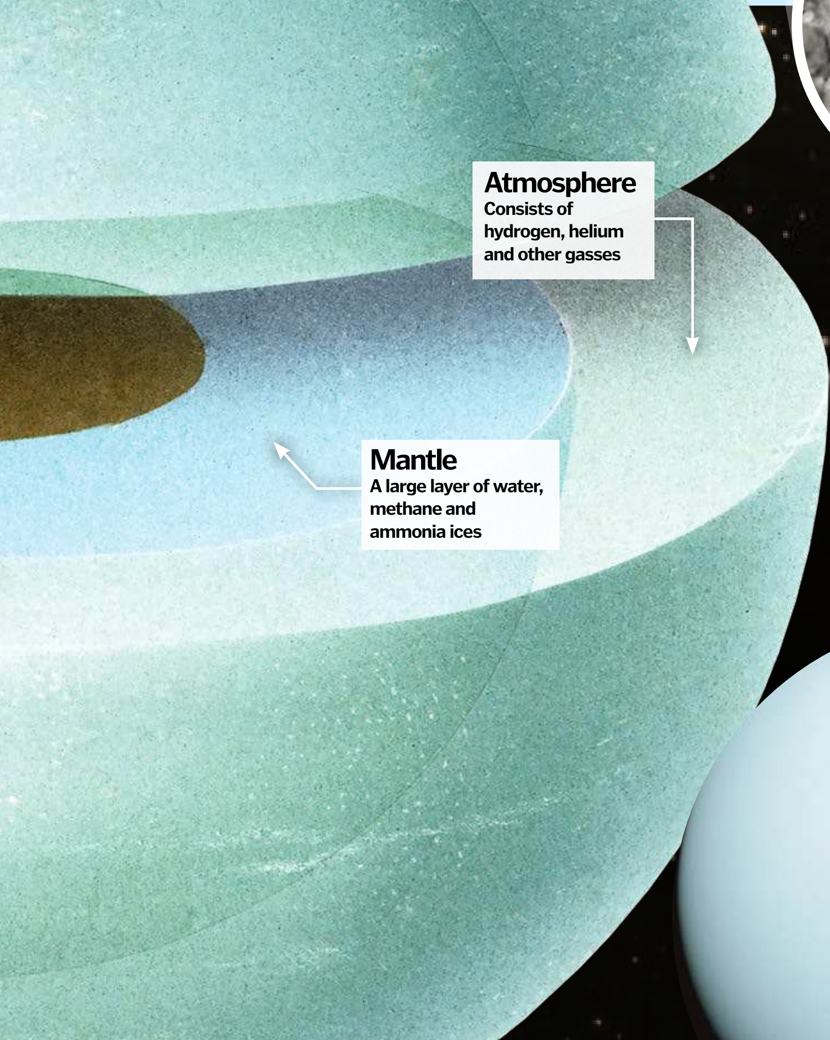
The smallest and innermost of Uranus's five major moons, Miranda is like no other moon in our Solar System

When the Voyager 2 passed by Uranus in 1986 it not only observed the planet but also many of its moons, coming close to its innermost Miranda at a distance of 32,000km. However, the images it recorded were not what were expected as on closer inspection it showed the satellite's surface consisted of a series of incongruous surface features that seemed to have been crushed together and butted up unnaturally. Miranda was an ancient terrain that seemed to have been constructed from various smaller segments from different time periods, instead of forming as one distinct whole at one time. Scientists have theorised that this was probably caused by a catastrophic collision in the moon's past that caused it to shatter into various pieces before then being reassembled in this disjointed way.



Verona Rupes

Found on Uranus' moon Miranda, this cliff face is estimated to be ten kilometres deep, almost ten times the depth of the Grand Canyon. This makes it the tallest known cliff in the entire Solar System

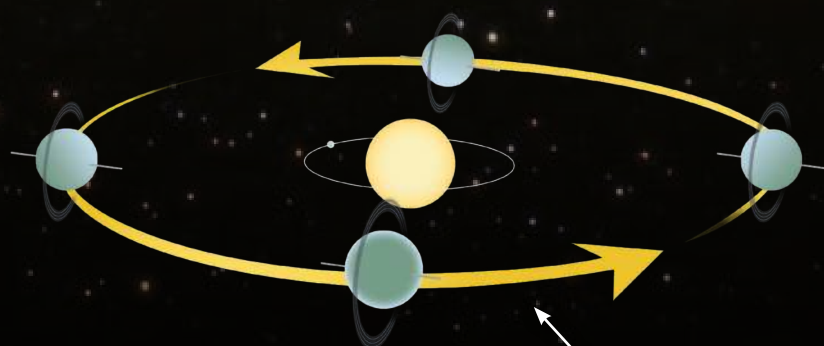


Atmosphere

Consists of hydrogen, helium and other gasses

Mantle

A large layer of water, methane and ammonia ices



4. Orbit

Uranus takes 84 Earth years to complete a single orbit around the Sun, through which it is permanently tilted on its side by 98° – a factor probably caused by a planetary-sized collision while it was still young. Due to its sideways tilt, each of the planet's poles points to the Sun for 21 years at a time, meaning that while one pole receives continuous sunlight, the other receives continuous darkness. The strength of the sunlight that Uranus receives on its orbit is 0.25 per cent of that which is received on Earth. There is a difference of 186 million kilometres between Uranus's aphelion (furthest point on an orbit from the Sun) and perihelion (closest point on an orbit).

3. Structure

Uranus consists of three distinct sections, an atmosphere of hydrogen, helium and other gases, an inner layer of water, methane and ammonia ices, and a small core consisting of rock and ice. Electric currents within its icy layer are postulated by astronomers to generate Uranus's magnetic field, which is offset by 58.6° from the planet's spin axis. Its large layers of gaseous hydrogen and constantly shifting methane and ammonia ices account for the planet's low mass compared to its volume.

Sizes…

Uranus' diameter is nearly five times that of Earth, with a mass that's equivalent to 14 and a half Earths

12,756.3km

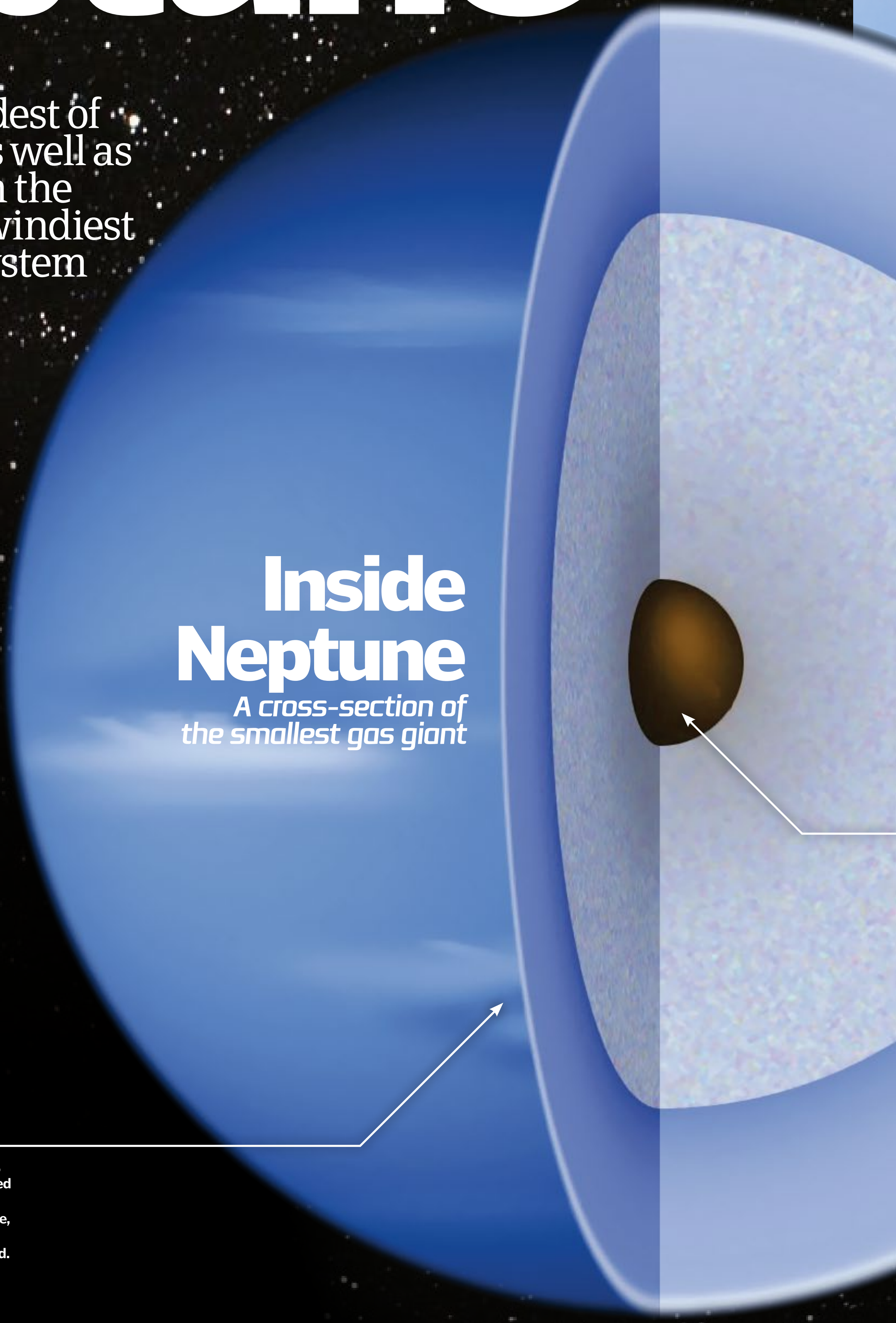
51,118km

Images courtesy of NASA

Neptune

The smallest and coldest of the four gas giants, as well as the most distant from the Sun, Neptune is the windiest planet in our Solar System

Over 4.5 billion kilometres from Earth and with an average temperature of -220°C, Neptune is the furthest planet from the Sun and the coldest in our Solar System, excluding the dwarf planet Pluto. It is a massive (49,532km in diameter) sphere of hydrogen, helium and methane gas, formed around a small but mass-heavy core of rock and ice that, despite its similar size and structure to its inner neighbour Uranus, differs in appearance dramatically, presenting its turbulent, violently windy atmosphere on its surface. Find out what makes Neptune so unique and volatile right here.



Inside Neptune

A cross-section of the smallest gas giant

A gigantic storm the size of Earth

5. Dark spot

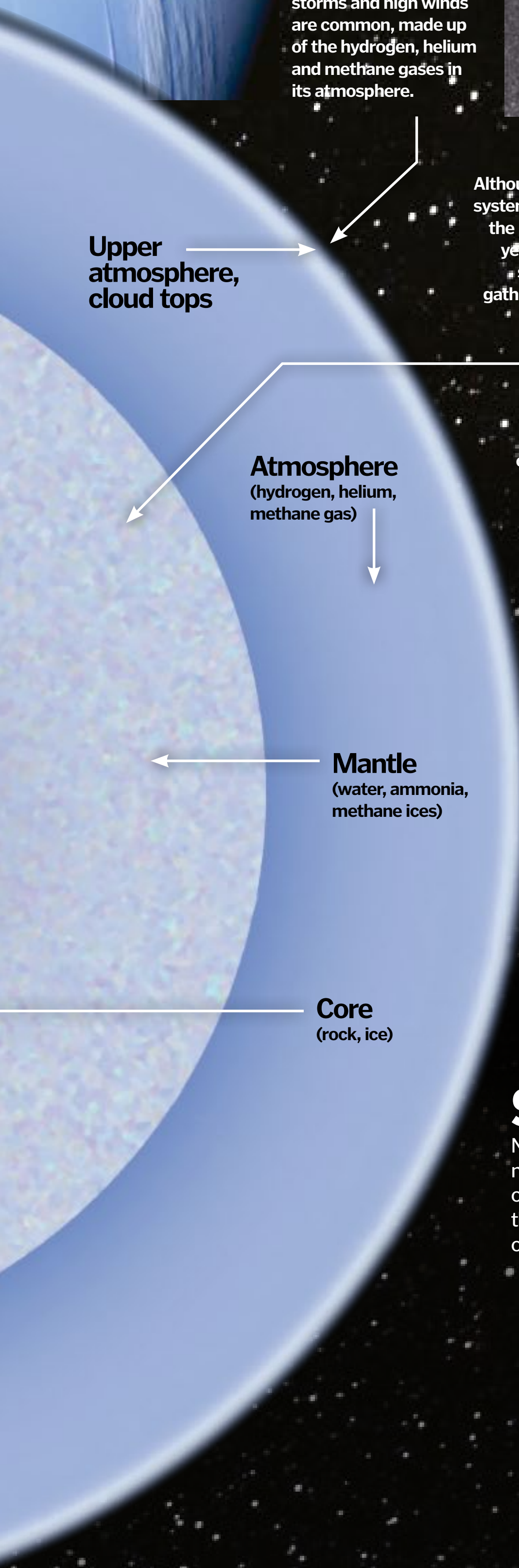
The Great Dark Spot, a gigantic, dark storm the size of Earth, was captured on film by the Voyager 2 spacecraft as it passed by Neptune in 1989. Storms of this size and magnitude are believed by scientists to be relatively common on this volatile, windy planet. However, when the Hubble Space Telescope tried to image the Great Dark Spot in 1996 it had disappeared.

1. Atmosphere

Despite its massive distance from the Sun (the Sun is over 900 times weaker on Neptune compared to on Earth), Neptune is host to a complex and active weather system driven by its internal heat source. Clouds, storms and high winds are common, made up of the hydrogen, helium and methane gases in its atmosphere.

2. Rings

Although not shown here, Neptune is actually a ring system, and is host to a series of six rings encircling the planet. The rings are made from tiny pieces of yet-to-be determined materials (probably rocks, stellar dust and numerous gases), which were gathered from nearby moons and phenomena and stretch a few kilometres across in width.



3. Structure

Neptune is very similar in size and composition to Uranus. Indeed, only 15 per cent of the planet's mass is hydrogen – contained within its shallow outer layer – with its main layer consisting of a mix of water, methane ice and ammonia, and its tiny central core postulated to be constructed purely out of rock. As with the other gas giants, the boundaries between layers are not clearly defined and change consistently.

4. Orbit

Neptune takes 164.8 Earth years to orbit the Sun and it is tilted to its orbital plane by 28.3 degrees, allowing its northern and southern poles to face the Sun in turn. The planet is also 30 times further from the Sun than Earth and presents the solar system's second most circular orbit, only beaten by Venus in the parity between its aphelion and perihelion distances.

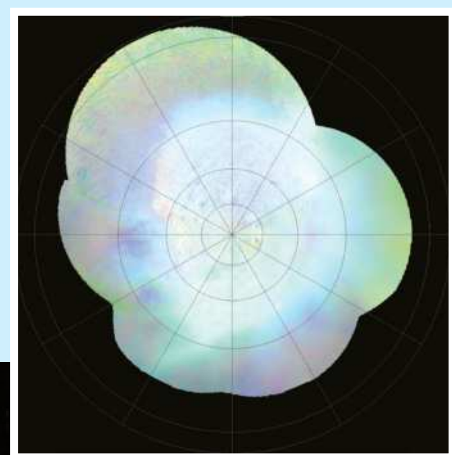
Dark carbonaceous dust litters Triton's south pole

Triton

Learning more about Neptune's massive moon

While Neptune has 13 moons in total (four in its ring system and nine out), it has only one major moon – Triton. Triton was the first of Neptune's moons to be discovered, just 17 days after the discovery of the planet was announced in 1846, and it is bigger than the dwarf planet Pluto. It follows a circular orbit around Neptune and exhibits a synchronous rotation, meaning that the same side always faces inwards. At both of its poles bands of nitrogen frost and snow are projected and redistributed by solar winds over its atmosphere and into space.

Triton is retrograde in motion, travelling in the opposite direction to Neptune's spin, and this scientists believe is evidence to its captured origin from elsewhere in the Solar System, rather than formation in line with its planetary centre. Geologically young, Triton is two parts rock to one part ice and has a liquid mantle core and crusty, icy, craterous surface. At its southern pole lies a region of dark patches caused by the heating of sub-surface nitrogen ice into gas that erupts through surface vents in geyser-like plumes, depositing carbonaceous dust over its surface.

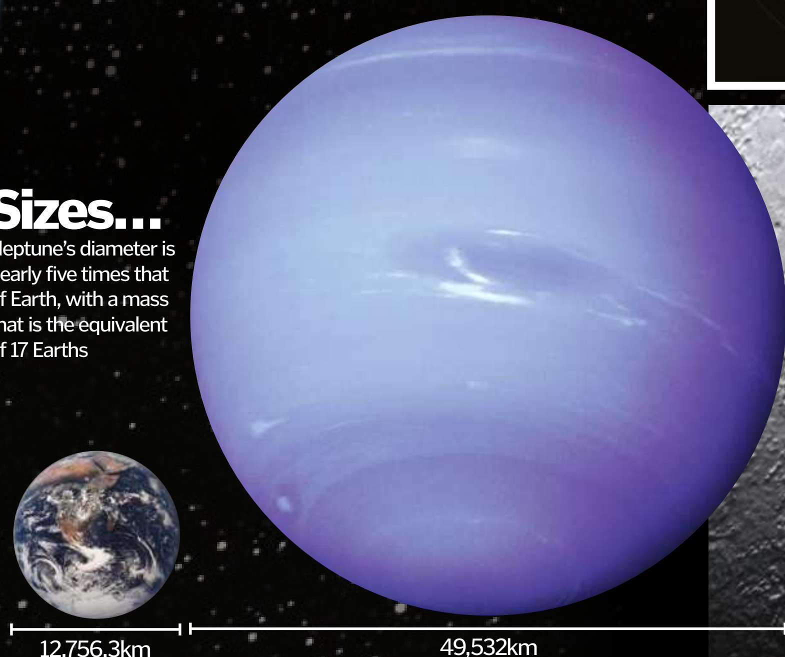


An image showing Triton's polar projection

Triton's icy, scarred surface

Sizes…

Neptune's diameter is nearly five times that of Earth, with a mass that is the equivalent of 17 Earths



Pluto

The elusive Planet X that became an ex-planet and still has many X factors

The astronomer Percival Lowell predicted the existence of a ninth planet in our solar system, beyond the orbit of Neptune. Lowell failed to find Planet X, but Clyde Tombaugh – using the Lowell Observatory in Arizona – confirmed his calculations. Shortly after Planet X's discovery back in January 1930 it was named Pluto. In 1978, it was determined that Lowell's theory based on the mass of Pluto and its effects on Uranus and Neptune were incorrect. Tombaugh's discovery was just a coincidence.

The dwarf planet Pluto takes a leisurely 248 years to orbit the Sun. Its highly elliptical orbit takes it to a maximum of 7.4 billion kilometres from the sun to as close as 4.5 billion kilometres. Twice in this orbit it is actually closer to the Sun than Neptune, as was the case from January 1979 to February 1999.

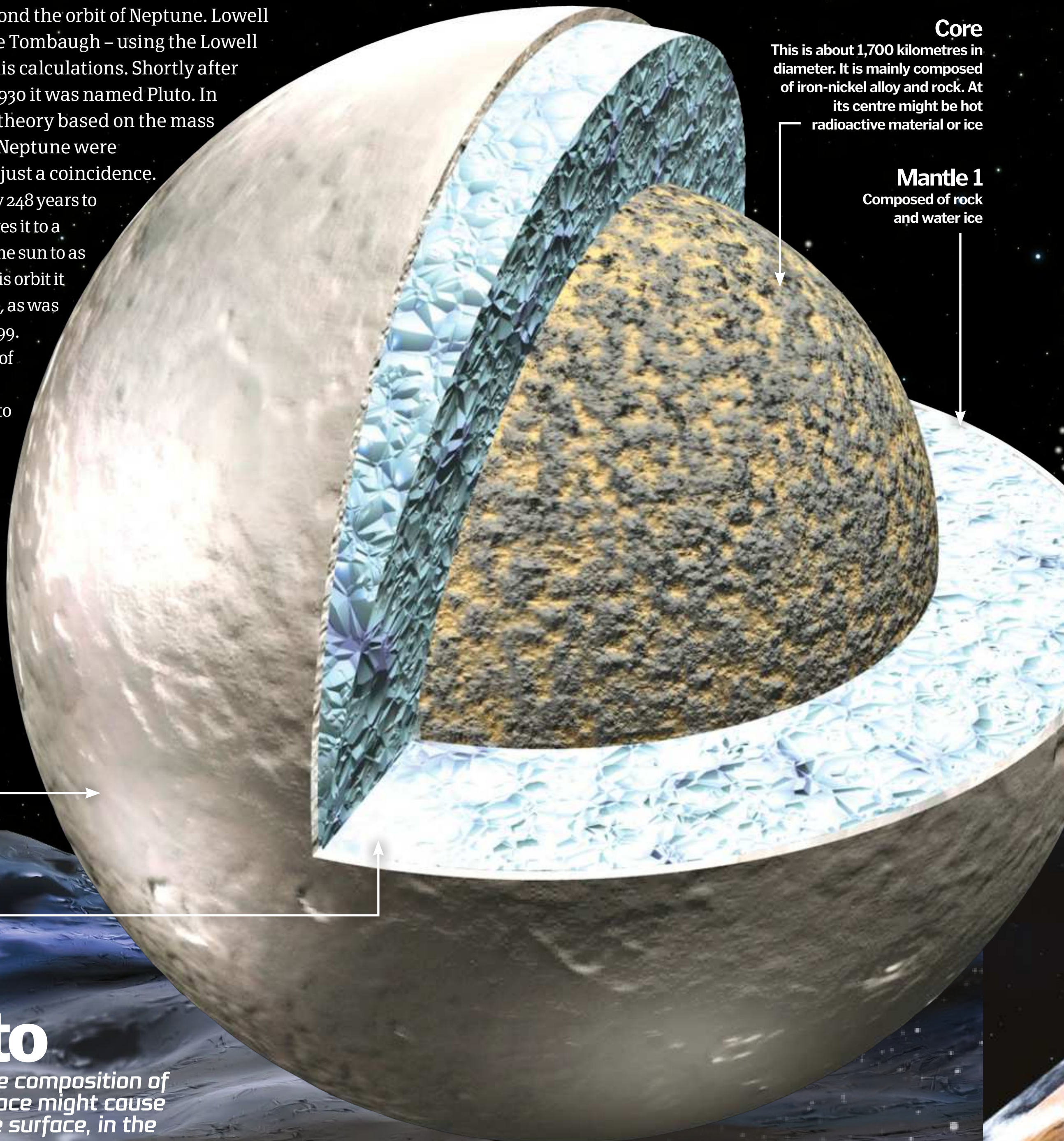
All the other planets orbit on the plane of the ecliptic, but Pluto's orbit is at an inclination of 17 degrees to this plane. Pluto is also unusual because it rotates at an angle of 122 degrees to its own axis, in a clockwise direction. This retrograde motion means it is spinning in an opposite direction to its counter-clockwise orbit around the Sun.

Previously, only the Hubble Space Telescope had obtained grainy pictures of its surface, and it wasn't until the arrival of the New Horizons spacecraft in 2015 that we found out much more about this cold and distant body.

Surface details

Using observations by the Hubble Space Telescope, and maps produced since the Eighties, it has been found that the surface of Pluto undergoes many large variations in brightness and colour.

From 1994 to 2003, the southern hemisphere darkened, while the northern hemisphere got brighter. It has a slightly less red colour than Mars, with an orange cast similar to Jupiter's moon Io. It got redder from 2000 to 2002, and other colour variations of dark orange, charcoal black and white have been observed. These seasonal variations are regarded as being due to the orbital eccentricity and axial tilt of Pluto that are reflecting topographic features and the flux of the frozen surface of the planet with its rarefied atmosphere.



Inside Pluto

So far, we know little about the composition of Pluto. Ice beneath Pluto's surface might cause movement and changes on the surface, in the same way glaciers do on Earth

The Statistics

134340 Pluto

© NASA

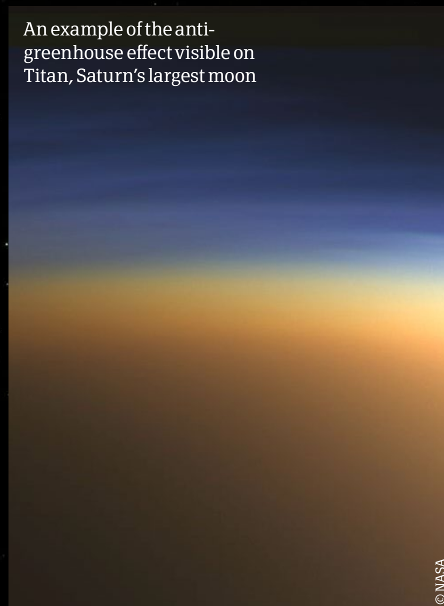
Diameter: 2,320km
Mass: 1.3 x 10^{22} kg
Density: 2 grams per cubic centimetre
Average surface temperature: -230°C or -382°F (44K)
Core temperature: Unknown
Average distance from the Sun: 5,913,520,000 km (39.5 AU)
Surface gravity: 0.067g
Moons: 3

Atmosphere

When Pluto's elongated orbit takes it relatively close to the Sun, the frozen nitrogen, methane and carbon monoxide on its surface sublimates into a tenuous gaseous form. This creates winds and clouds, but the weak gravitational force of Pluto means that it can escape into space and interact with its moon, Charon.

In the process of sublimation an anti-greenhouse effect is created, which lowers the temperature of Pluto to -230°C against the expected -220°C, which is the temperature of Charon. In the lower atmosphere, a concentration of methane creates a temperature inversion that makes the upper atmosphere warmer by three to 15 degrees every kilometre upwards. On average, the upper atmosphere is 50°C warmer than the surface of Pluto.

When Pluto's orbit takes it away from the Sun, the gaseous atmosphere freezes and falls to the surface.



An example of the anti-greenhouse effect visible on Titan, Saturn's largest moon

© NASA

What is a planet?

Pluto's status as a planet was safe until the Nineties. This was when huge 'hot Jupiter' extra-solar planets were discovered, and objects were observed beyond the orbit of Neptune that rivalled the size of Pluto. Faced with the dilemma of defining a planet the International Astronomical Union (IAU) decided that it must be spherical, that it orbits the Sun and is clear of any planetary neighbours. Consequently, the IAU reclassified Pluto as a dwarf planet on the 24 August 2006.

An image of Pluto, with Charon visible to the bottom-left

© NASA

Charon

Pluto's closest moon is Charon, which was discovered in 1978. It is 19,640 kilometres from Pluto, so from Earth they look like one planet. Charon has the same 6.4 day rate of rotation as Pluto so they always present the same face to each other. On Pluto, the surface facing Charon has more methane ice than the opposite face, which has more carbon monoxide and nitrogen ice.

Charon has a diameter of 1,210 kilometres, and has a grey surface with a bluer hue than Pluto. This indicates the surface could be covered in water ice rather than nitrogen ice. It is also speculated that methane has leaked from the grasp of its weak gravity to Pluto.

Plutoids

Plutoids, as defined by the IAU, are dwarf planets that orbit the Sun beyond Neptune, are round, have not cleared the neighbourhood of other similar bodies, and are not satellites of another planetary body. There could be at least 70 trans-Neptunian objects (TNOs) that might be plutoids.

So far only a few have been found and named. Besides Pluto, Makemake, Haumea and Eris have been classified as plutoids. Mike Brown and his Caltech team at the Palomar Observatory discovered them all in 2005. Eris is virtually the same size as Pluto and might have been regarded as a planet before the new classification system came into effect.

Sizes

Earth diameter:
8,000 miles
Pluto diameter:
1,400 miles

An artist's impression of the New Horizons craft

© NASA

Europa

Our greatest chance of finding life is possibly on this moon of Jupiter

One of Jupiter's four largest moons – the others being Io, Ganymede and Callisto – Europa is notable for its icy surface with a theorised ocean underneath. The moons all keep the same face towards Jupiter as they orbit. The layer of ice that encapsulates Europa's entire surface is as little as 5-100 miles thick. It has one of the smoothest surfaces in the solar system, with its features such as valleys and hills no larger or deeper than a few hundred metres. This suggests it is young and still actively forming like Earth.

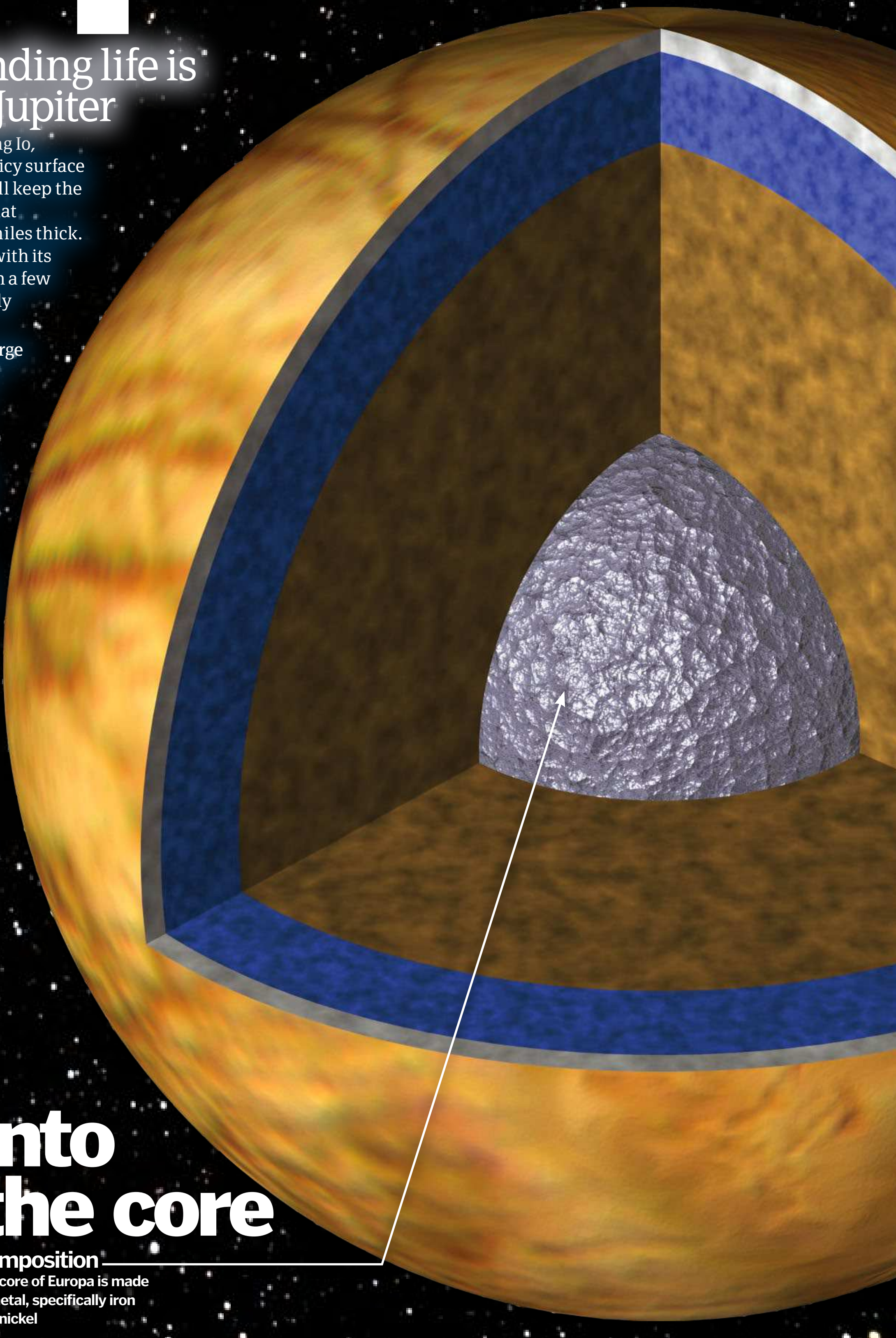
Most of Europa is made of rock, although its core has a large iron content. Gravitational forces from Jupiter and its other three largest moons have given Europa a hot interior in a process known as tidal heating, similar to how tides are created on Earth as our moon stretches and pulls the oceans. Europa has a very thin atmosphere made of just oxygen created by particles emitted from the radiation of Jupiter striking the surface and producing water vapour.

Due to there being almost no atmosphere on Europa, which is not much smaller than our moon, the temperature on the surface drops to -162°C at the equator and possibly as low as -220°C at the poles. Absolute zero is not much colder at -273.15°C. A few miles down into Europa's ocean, the temperature could still be as cold as -30°C or as high as 0°C, meaning that any life would have to adapt to these freezing temperatures.

The large amount of radiation Jupiter exerts can severely damage any probe attempting to reach Europa. One of the only missions to study the moon was the Galileo space probe, named after the astronomer Galileo who discovered Jupiter's four largest moons in one week in 1610. It journeyed between Jupiter and its moons from 1995 to 2003, providing much of the information we know about Europa today.

This picture, taken by the Cassini spacecraft, shows Europa casting a shadow on Jupiter

Images courtesy of NASA

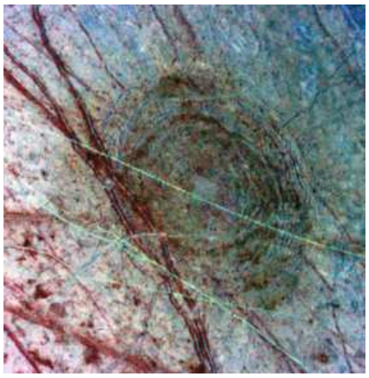


Into the core

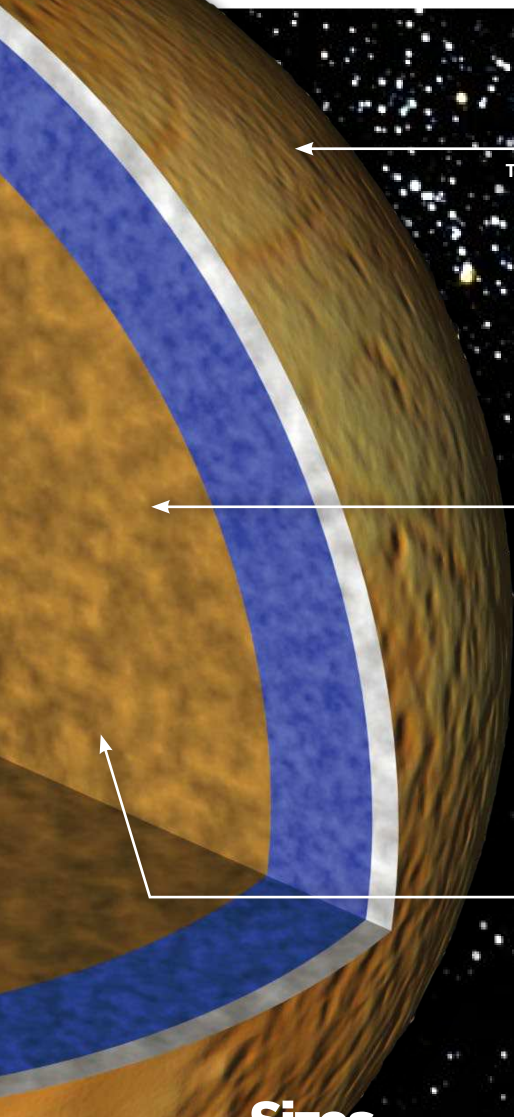
Composition
The core of Europa is made of metal, specifically iron and nickel

Life on Europa

The lack of impact craters on the surface of Europa but the presence of fissures and cracks means that something other than meteorites must be fracturing and altering the ice. This has led scientists to believe there is an ocean of water beneath the icy surface of Europa. It is in this ocean where life could reside. Previously, it was thought animals required sunlight to live, but the discovery of creatures living off small bacteria at the bottom of Earth's oceans have raised the possibility that animals as large as fish could be living below Europa's surface. There are two main theories as to how Europa's ocean could look, shown in the 'Under the surface' boxout.

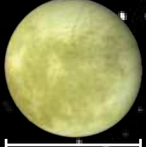


Visible cracks suggest there is water beneath the surface



Sizes…

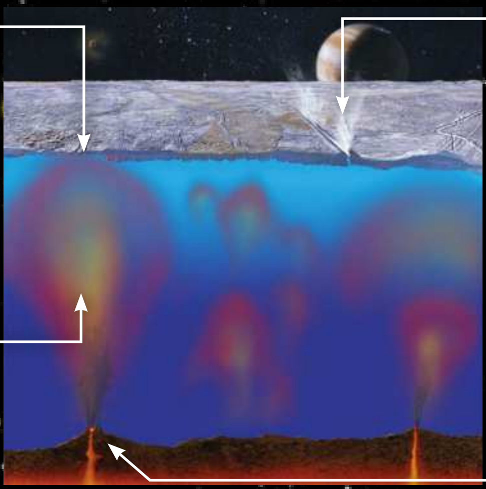
Europa's diameter is a quarter of Earth's with a mass equal to 0.008 of Earth's



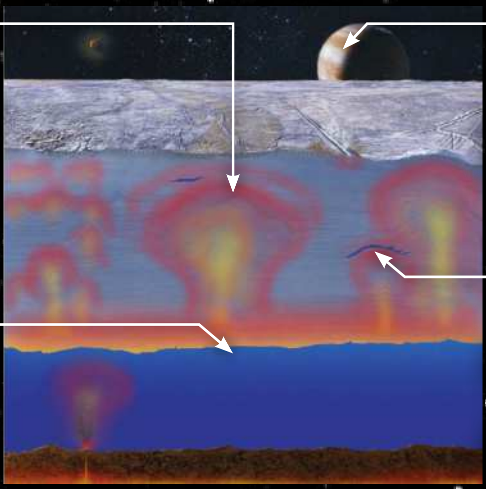
Under the surface

The two theories of Europa's structure

Thin ice sheet



Thick ice sheet



Life on Titan

Is there life among the chaotic, carbon-based chemistry of this ice-cold world?

With a thick atmosphere teeming with organic compounds and stable liquids on its surface, many believe that Titan is among the most likely locations for life. We know that sunlight destroys methane so something must be replacing Titan's atmospheric content; could this be an extraterrestrial life form?

Of the 62 different moons that orbit Saturn, none possess the same potential to change the way we see our universe as Titan. Labelled by some as the most mysterious object in our Solar System, this moon is the largest orbiting Saturn and is the second largest overall; beaten only by Jupiter's moon Ganymede.

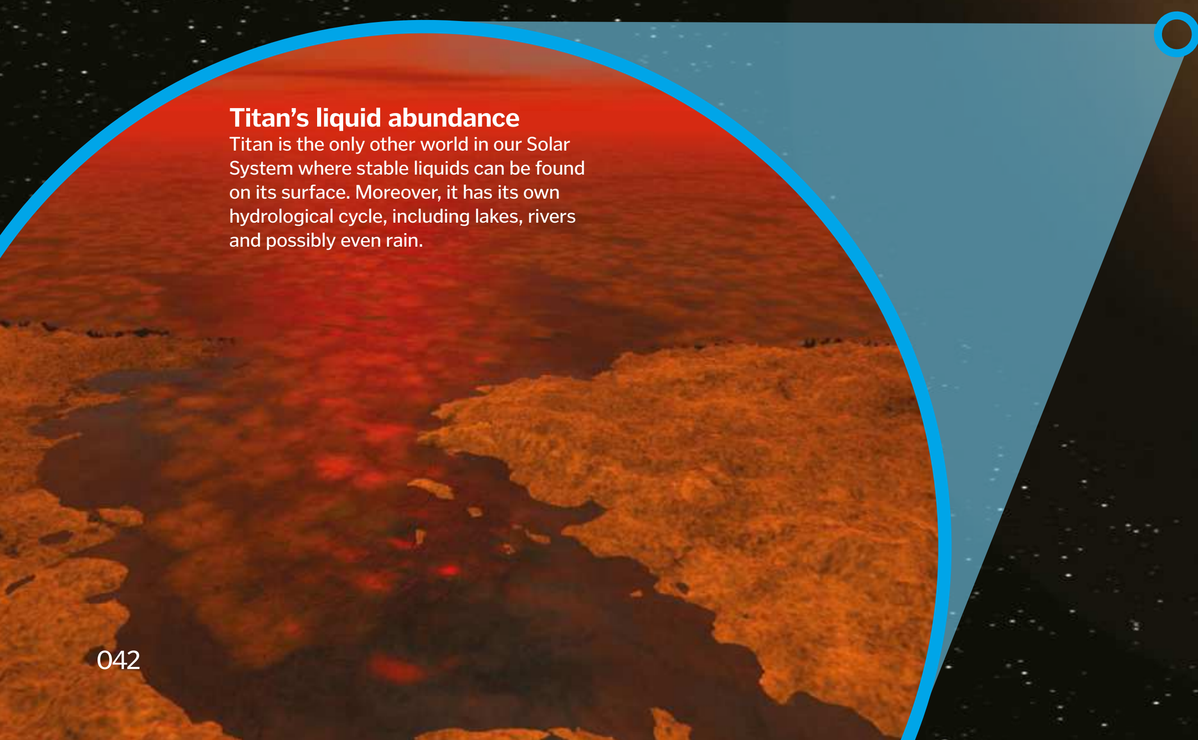
The surface of Titan shares many similarities with Earth. It has lakes, seas, rivers, shorelines and highlands. The confirmation of liquid on Titan's surface was a hugely significant finding. However, this surface liquid is not water, it is methane, one of many hydrocarbons that reside on this moon. It is also thought that a hydrological cycle is present, which revolves around methane and its conversion from liquid to gas and back again. This Earth-like climate system reinforces Titan's status as the most similar planetary body to our planet.

The majority of our knowledge of Titan can be credited to the Cassini-Huygens mission. The Cassini spacecraft was launched in 1997, tasked with the examination of Saturn and its surrounding rings and moons. Equipped with the Huygens probe, Cassini reached Saturn seven years later, and began its observations of this distant part of the Solar System. On 14 January 2005 the Huygens probe parachuted down through Titan's thick, orange haze of an atmosphere, and became the first object to land in the outer Solar System.

Many experts argue that the key to life is liquid, as we know the chemical processes required for life need a liquid medium. On Earth we know this liquid is water, but on Titan it could well be methane. NASA is planning future missions to Titan in the hope of delving deeper into the mysteries of this unusual planetary body. In the coming decades, they hope to reveal the first signs of life on Titan, using the latest investigative space technology to explore its monstrous seas and freezing landscape.

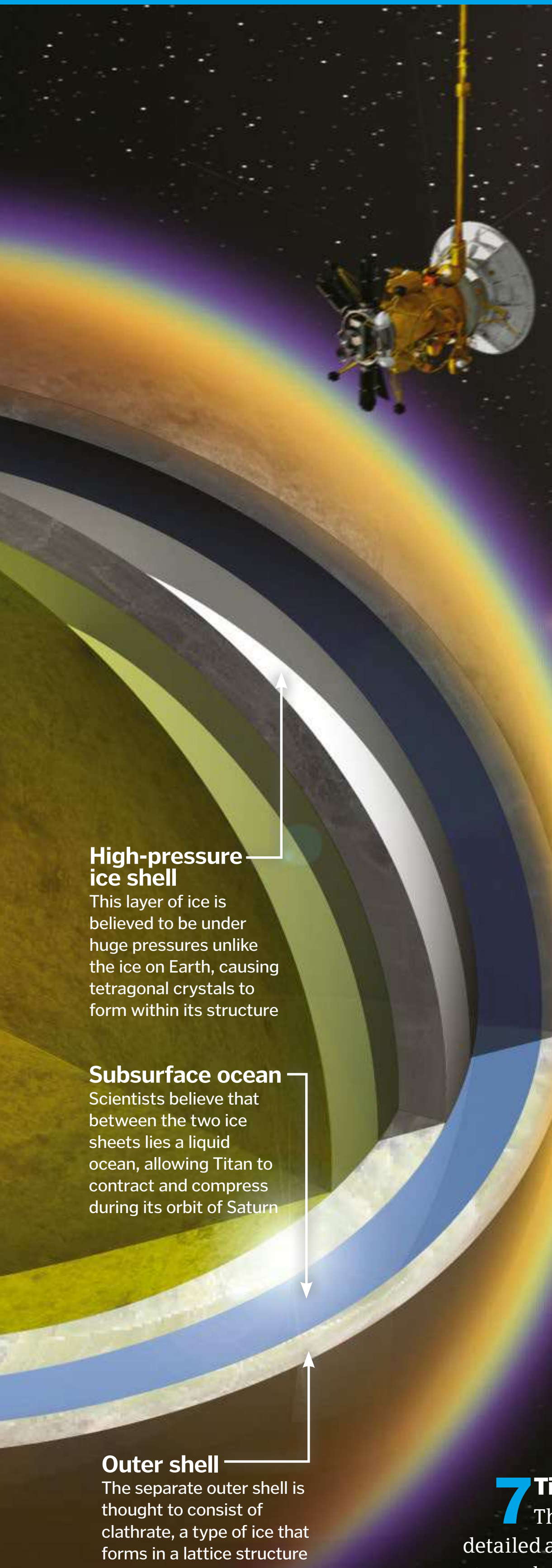
Core
The core is thought to comprise of silicate rock, and possess a radius in the range of 2,000 kilometres (1,243 miles)

Organic-rich surface
Both the atmosphere and surface of Titan are rich with organics, including complex hydrocarbons. Methane rain may form an icy crust on the surface



Titan's liquid abundance
Titan is the only other world in our Solar System where stable liquids can be found on its surface. Moreover, it has its own hydrological cycle, including lakes, rivers and possibly even rain.

Ten things we've learned from the Huygens probe



1 Titan's atmospheric profile

The Huygens Atmospheric Structure Instrument (HASI) was able to perform the first direct measurements of Titan's atmosphere. It determined the atmospheric pressure, temperature and density, from 1,400 kilometres (870 miles) above the surface.

2 Rotating winds

Throughout Huygens' descent to Titan's surface, wind measurements were taken. At altitudes greater than 45 kilometres (28 miles), wind speeds were far greater than the moon's rotational speed, confirming the predicted superrotation of its atmosphere.

3 Mysterious methane

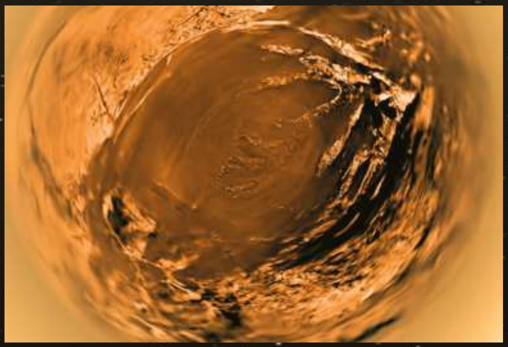
Although Huygens was unable to unearth the source of methane on Titan or how it is replenished, it did confirm its presence both in the atmosphere and on the surface.

4 Origins of nitrogen atmosphere

Prior to Huygens, the Voyager mission data had implied that Titan's atmosphere contained nitrogen. Huygens was able to prove this, its data suggesting that it originated from ammonia or another nitrogen-containing compound.

5 Cryovolcanism

Huygens detected argon-40, which originates from a potassium isotope found in rocks. This is a strong indication of geological activity, potentially in the form of cryovolcanoes, which erupt volatile liquids rather than molten lava.



6 Titan's haze

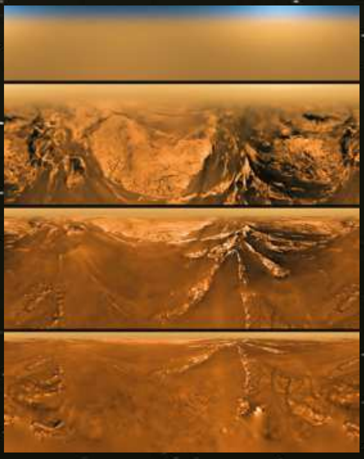
Huygens showed that Titan's blanket of orange haze extended all the way down to the moon's surface. It also revealed the size and optical properties of Titan's haze particles.

7 Tiny aerosols

The Huygens probe performed detailed analysis of the aerosols in Titan's atmosphere, by heating them in an oven and identifying the gases released. Both ammonia and hydrogen cyanide were detected.

8 Dry river beds

A definite highlight of Huygens' work was the capture of several hundred images of Titan's surface. Dry riverbeds and lakes were pictured for the first time, alongside highland terrain and rounded cobbles.



9 Evidence of subsurface ocean

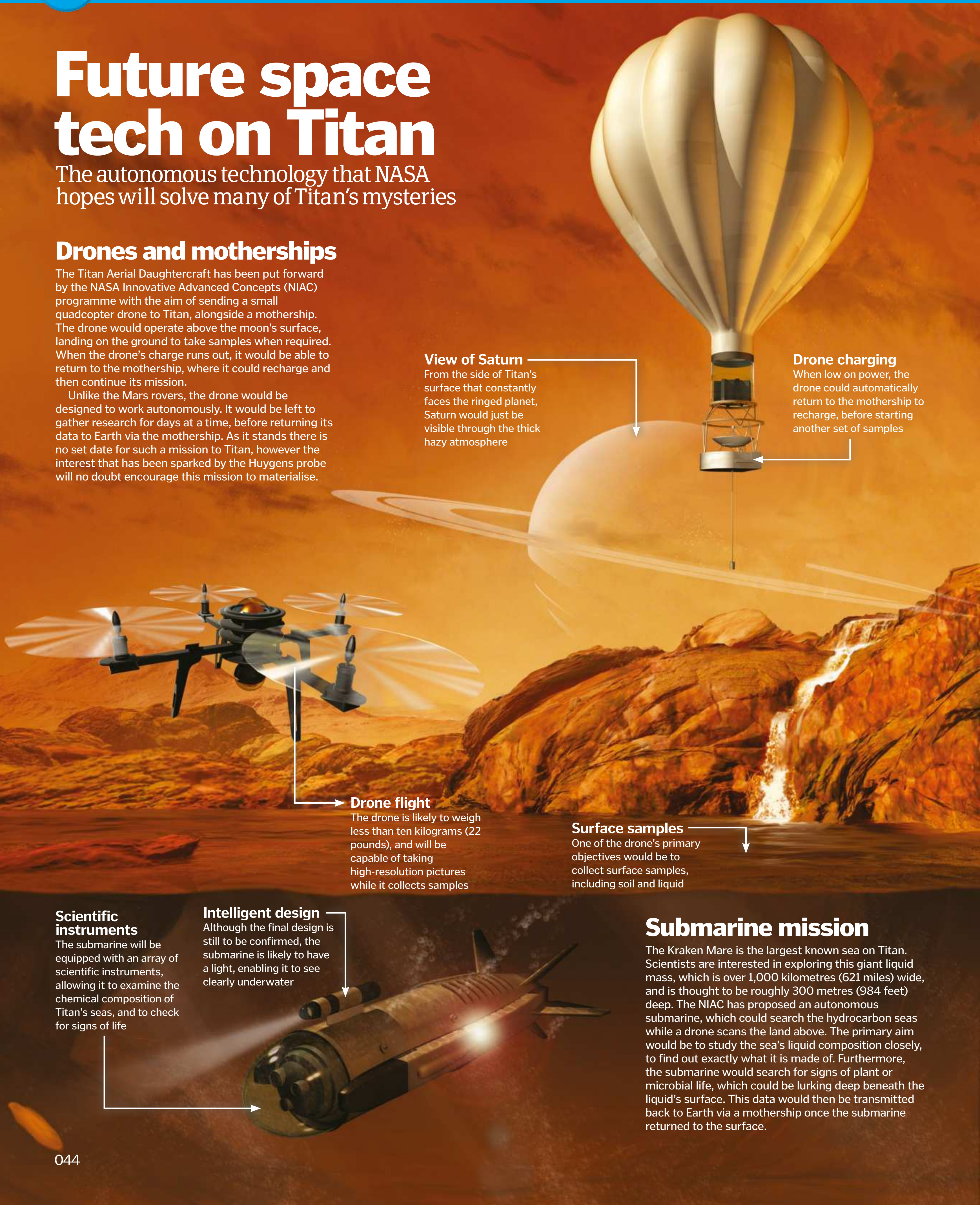
Although the probe didn't detect any lightning, an unusual source of electrical excitation within the moon's atmosphere was identified. Scientists believe this could be attributed to a conductive, subsurface ocean, deep beneath Titan's surface.

10 Distinctive dunes

Initially, scientists struggled to locate Huygens' landing site using images from the Cassini orbiter. This was due to the presence of vast dunes, thought to be composed of sand-sized hydrocarbons.

Future space tech on Titan

The autonomous technology that NASA hopes will solve many of Titan's mysteries



Drones and motherships

The Titan Aerial Daughtercraft has been put forward by the NASA Innovative Advanced Concepts (NIAC) programme with the aim of sending a small quadcopter drone to Titan, alongside a mothership. The drone would operate above the moon's surface, landing on the ground to take samples when required. When the drone's charge runs out, it would be able to return to the mothership, where it could recharge and then continue its mission.

Unlike the Mars rovers, the drone would be designed to work autonomously. It would be left to gather research for days at a time, before returning its data to Earth via the mothership. As it stands there is no set date for such a mission to Titan, however the interest that has been sparked by the Huygens probe will no doubt encourage this mission to materialise.

View of Saturn

From the side of Titan's surface that constantly faces the ringed planet, Saturn would just be visible through the thick hazy atmosphere

Drone charging

When low on power, the drone could automatically return to the mothership to recharge, before starting another set of samples

Drone flight

The drone is likely to weigh less than ten kilograms (22 pounds), and will be capable of taking high-resolution pictures while it collects samples

Surface samples

One of the drone's primary objectives would be to collect surface samples, including soil and liquid

Scientific instruments

The submarine will be equipped with an array of scientific instruments, allowing it to examine the chemical composition of Titan's seas, and to check for signs of life

Intelligent design

Although the final design is still to be confirmed, the submarine is likely to have a light, enabling it to see clearly underwater

Submarine mission

The Kraken Mare is the largest known sea on Titan. Scientists are interested in exploring this giant liquid mass, which is over 1,000 kilometres (621 miles) wide, and is thought to be roughly 300 metres (984 feet) deep. The NIAC has proposed an autonomous submarine, which could search the hydrocarbon seas while a drone scans the land above. The primary aim would be to study the sea's liquid composition closely, to find out exactly what it is made of. Furthermore, the submarine would search for signs of plant or microbial life, which could be lurking deep beneath the liquid's surface. This data would then be transmitted back to Earth via a mothership once the submarine returned to the surface.

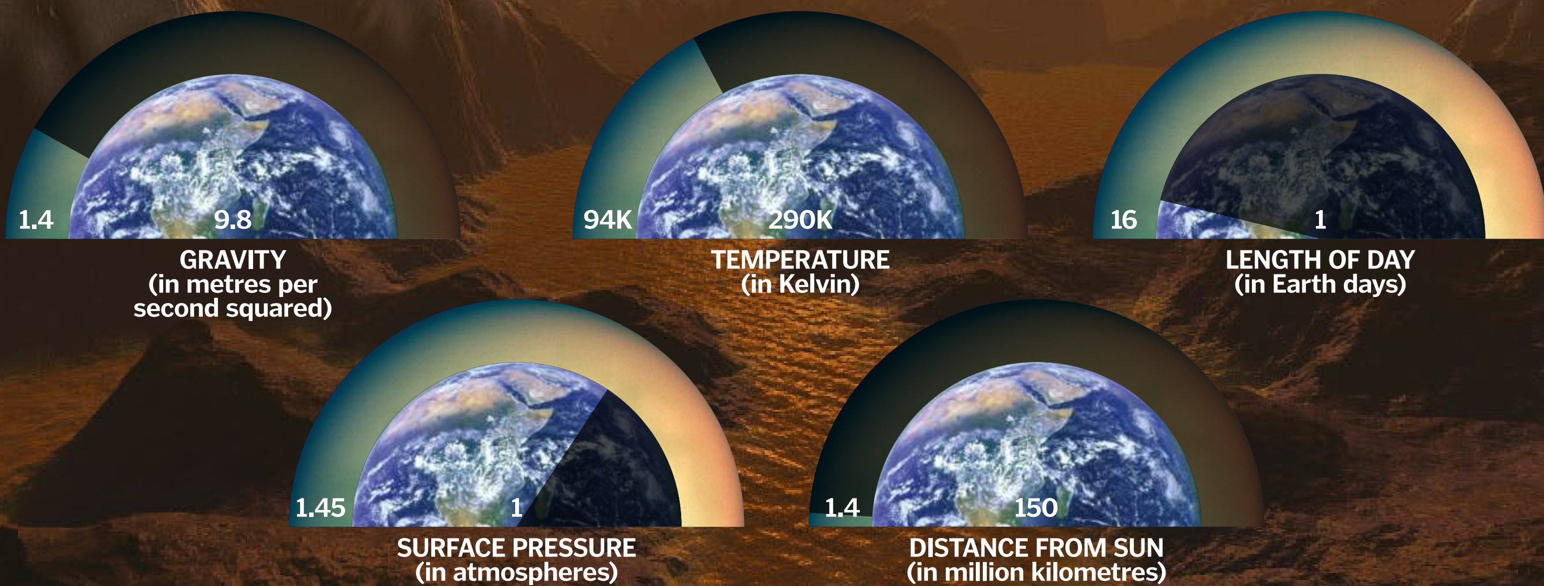
Could we survive on Titan?

It's fair to say that Titan is one of the most Earth-like worlds we've visited, which raises the question of whether humans could colonise it. There are a number of possible benefits, none of which are greater than the potential use of Titan's natural resources. In fact, data from Cassini suggests that Titan has more liquid hydrocarbons than all the known natural gas and oil resources on Earth.

If there is a large volume of water trapped beneath this moon's surface, it could be used to generate breathable oxygen. Furthermore, by combining Titan's water and methane, it would be possible to create rocket fuel that could be used as a power supply. While nitrogen, methane and ammonia – all thought to be present on Saturn's largest moon – could be used to produce fertiliser to help grow food.

There are a number of issues that humans on Titan would face. The extreme temperatures mean that we would need large heat generators and insulation units just to stop ourselves from freezing. The effects of living in lower gravity might also cause long-term issues; studies are currently being conducted to examine this.

In spite of that, Titan may still be a better choice than Mars. It already has a dense, protective atmosphere; Mars will require extensive terraforming before an atmosphere of any kind can be created. Mars also lacks natural resources, and unlike Titan, does not benefit from an induced magnetosphere to deflect the harmful solar winds.



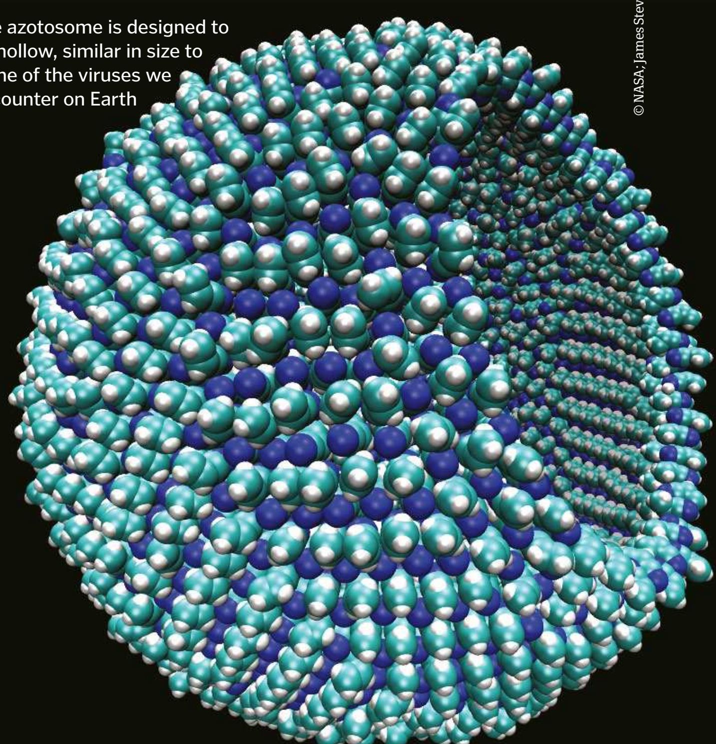
Engineering a template for life

See the cellular design that could thrive in the harsh conditions on Titan

When astronomers search for extraterrestrial life in the Solar System, they focus on one area in particular. This area is known as the circumstellar habitable zone, which is the small region around the Sun in which liquid water can exist.

But what if life could exist without water? This thought inspired scientists to create a cellular structure based on methane, which has a much lower freezing point than water and is abundant on Titan. They named their conceptual structure the 'azotosome'.

Cells on Earth all comprise of a phospholipid bilayer membrane, which houses the insides of every cell known to us. This water-based structure would not be able to function on Titan, due to the extreme temperatures. The azotosome is made up of carbon, nitrogen and hydrogen, all of which exist in the seas of Titan. The next step for these pioneering chemical engineers and astronomers is to show how these cells would function within Titan's methane environment, in particular how they might reproduce and metabolise.



The azotosome is designed to be hollow, similar in size to some of the viruses we encounter on Earth

Dwarf planets

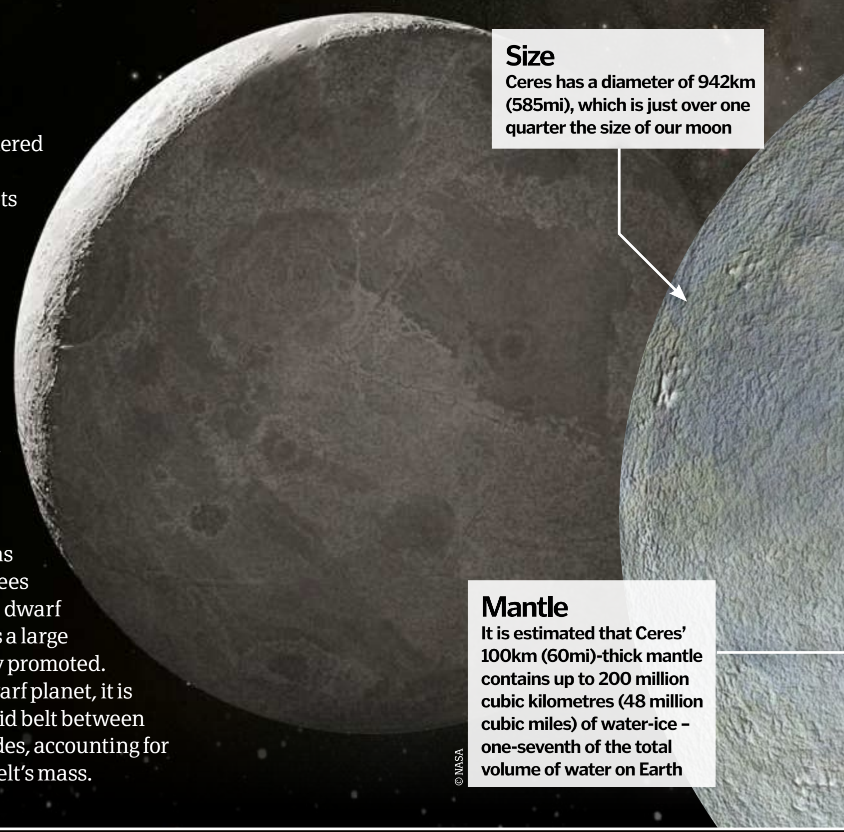
What is a dwarf planet and how is it distinguished from other celestial bodies?

When is a planet not a planet? Well, it's not as simple as you might think. Defining a planet into a particular category isn't easy, with the debate continuing to rage as to how exactly planets should be classified. According to the International Astronomical Union (IAU), dwarf planets are spherical objects in orbit around the Sun that are not moons, but they share their orbits with other debris which they have not been able to clear. It was the latter point that let Pluto down back in 2006, as it has other bodies within its orbit that it has not gathered. In addition, many bodies were discovered that were larger than Pluto, such as Eris, ultimately leading to its reclassification.

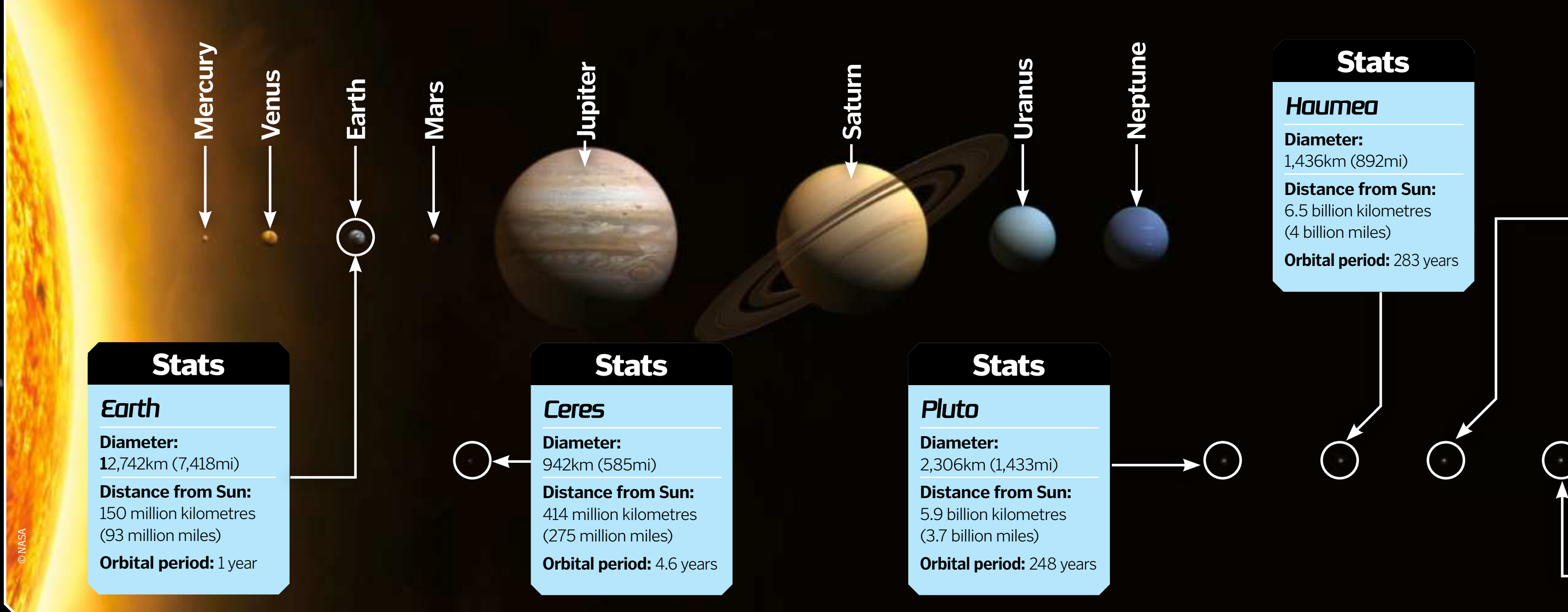
In simple terms, a dwarf planet can be regarded as a spherical object in our solar system exhibiting all or some of the properties of a planet, but lacking the necessary gravitational strength to have pulled other local objects into its influence.

There are currently five recognised dwarf planets in our solar system – these being Pluto, Eris, Makemake, Haumea and Ceres – but dozens more in the Kuiper belt, a disc-shaped region beyond Neptune, and the Oort cloud at the outer edge of the solar system, are being considered as candidates.

The five official dwarf planets and their unofficial brothers vary drastically in both composition and appearance, just as the main eight planets of the solar system do. Pluto is the only one of the five known to have its own moon – Charon, while Eris is the coldest of the bunch (and, indeed, the coldest known object in the solar system), with its surface temperature reaching as low as -250 degrees Celsius (-418 degrees Fahrenheit). Also of note is the dwarf planet Ceres, once regarded as a large spherical asteroid but recently promoted. Despite being the smallest dwarf planet, it is the largest object in the asteroid belt between Mars and Jupiter where it resides, accounting for about a quarter of the entire belt's mass.

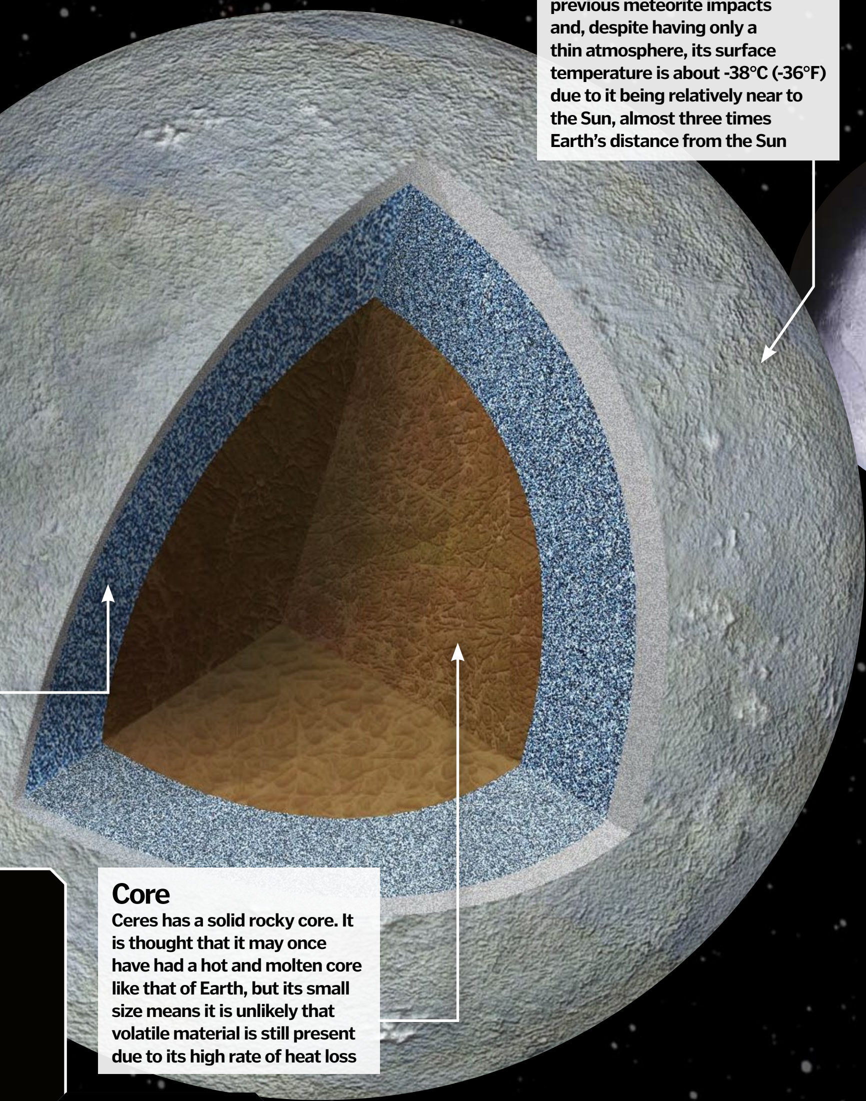


How do the dwarf planets size up to Earth?



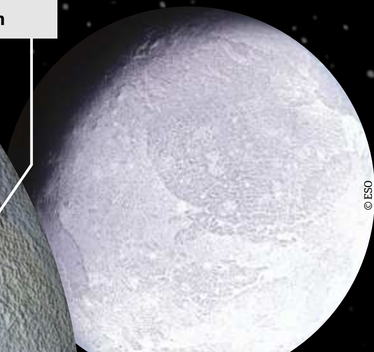
Inside Ceres

What's going on within the smallest dwarf planet in our solar system?



Surface
Ceres' surface bears marks of previous meteorite impacts and, despite having only a thin atmosphere, its surface temperature is about -38°C (-36°F) due to it being relatively near to the Sun, almost three times Earth's distance from the Sun

Core
Ceres has a solid rocky core. It is thought that it may once have had a hot and molten core like that of Earth, but its small size means it is unlikely that volatile material is still present due to its high rate of heat loss



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Stats

Makemake

Diameter: 1,500km (932mi)

Distance from Sun: 6.9 billion kilometres (4.3 billion miles)

Orbital period: 310 years

Stats

Eris

Diameter: 2,326km (1,445mi)

Distance from Sun: 10.1 billion kilometres (6.3 billion miles)

Orbital period: 557 years

NASA's Dawn spacecraft was the first to visit a dwarf planet, arriving at Ceres in 2015

WHAT TYPE OF PLANET ARE YOU?

Are you a terrestrial planet, a gas giant or a dwarf planet? Or something else? Have a go at our flowchart below to find out…

START
ARE YOU IN ORBIT AROUND THE SUN?
YES – NO

ARE YOU SPHERICAL?
YES – NO

ARE YOU ICY?
YES – NO

ARE YOU ALSO IN ORBIT AROUND A PLANET?
YES – NO

HAVE YOU CLEARED YOUR NEIGHBOURHOOD?
YES – NO

ARE YOU MOSTLY MADE OF ROCK?
YES – NO

YOU ARE… AN EXTRASOLAR PLANET
You are not from our solar system, and yet to be properly classified. You could be a super-Earth, or maybe you're made entirely of diamond. Nobody knows; you'll just have to wait to be found. Mysterious.

YOU ARE… A MOON
You are a natural satellite that orbits a planet/dwarf planet. You might be the only moon or you may be one of many. You were pulled into orbit during the planet's formation and are considerably smaller than your host. Clingy.

YOU ARE… AN ASTEROID
You are a prolific potato-shaped rocky object. You're probably located in either the asteroid belt between Jupiter and Mars or the Kuiper belt beyond Uranus, where more than 90 per cent of your kind live. Sociable.

YOU ARE… A TERRESTRIAL PLANET
You could be one of the rocky planets Mars, Earth, Venus or Mercury. You have a molten iron core and an atmosphere. On Venus, the climate is super-hot, but Mercury's is very cold. Atmospheric.

YOU ARE… A COMET
You're an irregular shape made mostly of ice, which melts and forms a dust tail. You have a separate tail composed of gas that always flows away from the Sun regardless of which direction you are travelling. Breezy.

YOU ARE… A GAS GIANT
You may be Jupiter, Saturn, Uranus or Neptune, the giants composed mostly of gas. You've cleared away all objects in your vicinity and exert an influence on everything around you due to your extremely high mass. Powerful.

YOU ARE… A DWARF PLANET
You're bigger than an asteroid and spherical but generally smaller than a 'proper' planet. You don't orbit anything but the Sun, however, you haven't managed to clear all local debris (or it hasn't yet formed into moons). Weakling.

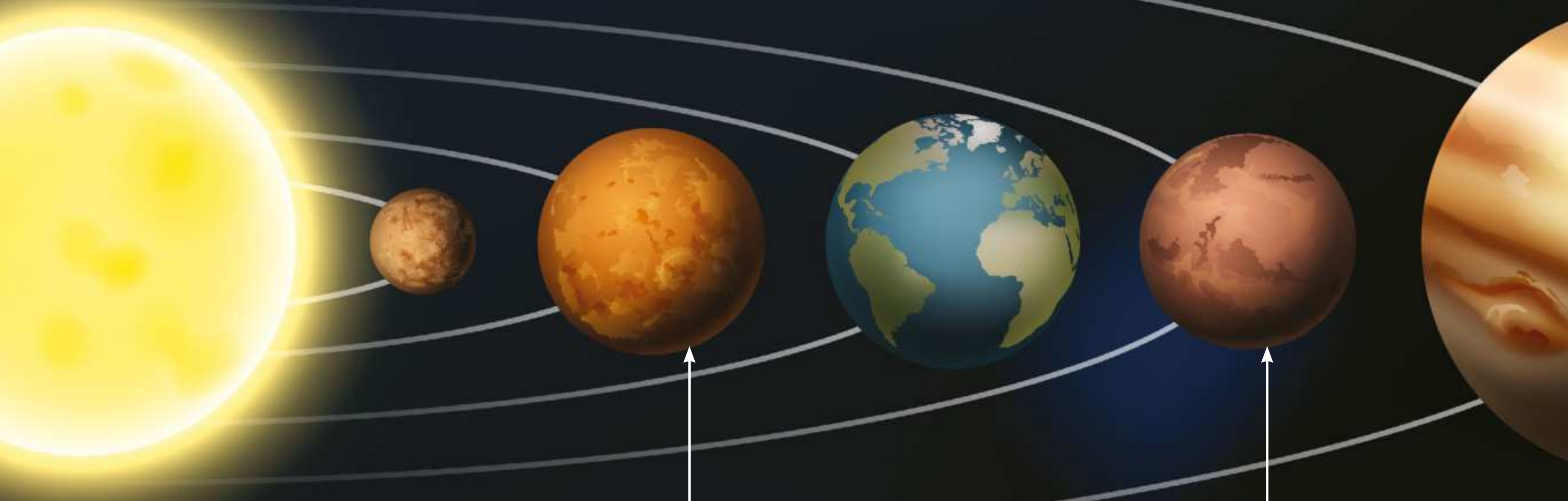
Auroras on other planets

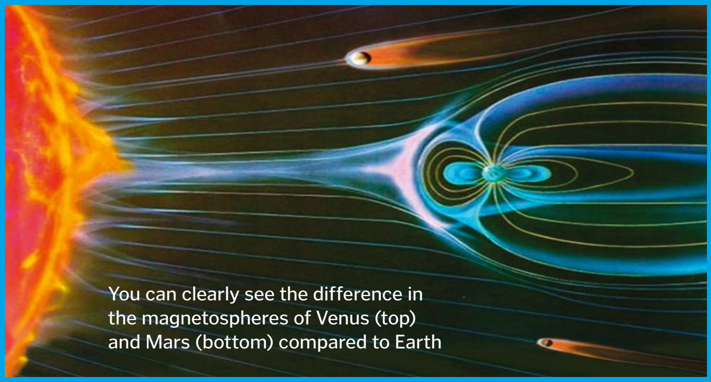
Find out what causes these magnificent light shows on the other planets in our Solar System

For many years, the auroras seen on our planet were thought to be the souls of the dead moving to the afterlife. An aurora on Earth is actually caused by the Sun and can be thought of as a form of space weather. Solar winds hit Earth with highly charged particles, but our planet's magnetic field deflects most of them before they reach the atmosphere. Every so often these winds are boosted by solar flares or coronal mass ejections, which release huge amounts of plasma.

When these intense solar winds reach Earth, some of the ionised particles get trapped in the magnetic field. These particles are then accelerated along the field lines toward the poles where they can enter the upper atmosphere, colliding with gas particles that cause them to emit bright light. This process creates the mesmerising aurora borealis and aurora australis, more commonly known as the northern lights and the southern lights respectively.

On Jupiter, Saturn, Uranus and Neptune, auroras form in a similar manner to how they form on Earth. However, on Mars and Venus they form very differently, as neither of these planets possess a significant magnetic field.

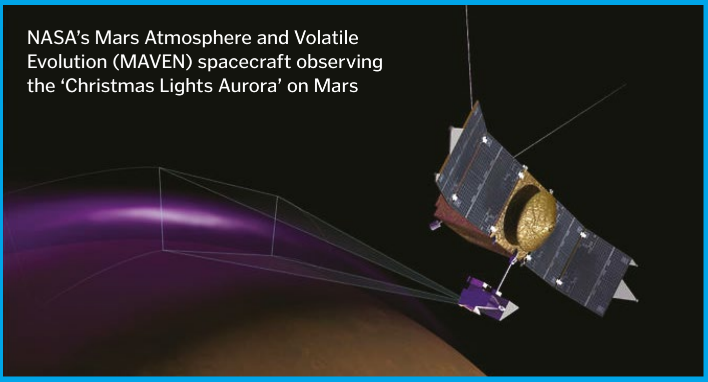




You can clearly see the difference in the magnetospheres of Venus (top) and Mars (bottom) compared to Earth

Venus

Similar to Mars, Venus does not possess its own planetary magnetic field, but flashes of light from the planet have been identified as auroras. Scientists have found that the same process that causes auroras on Earth can form a gigantic magnetic bubble around Venus, allowing auroras to occur. This is possible due to Venus having a magnetotail, which was formed by ionosphere and solar wind interaction. The fact that magnetic reconnection can occur within Venus' magnetotail suggests auroras are the cause of the light that scientists have observed emitting from this planet.

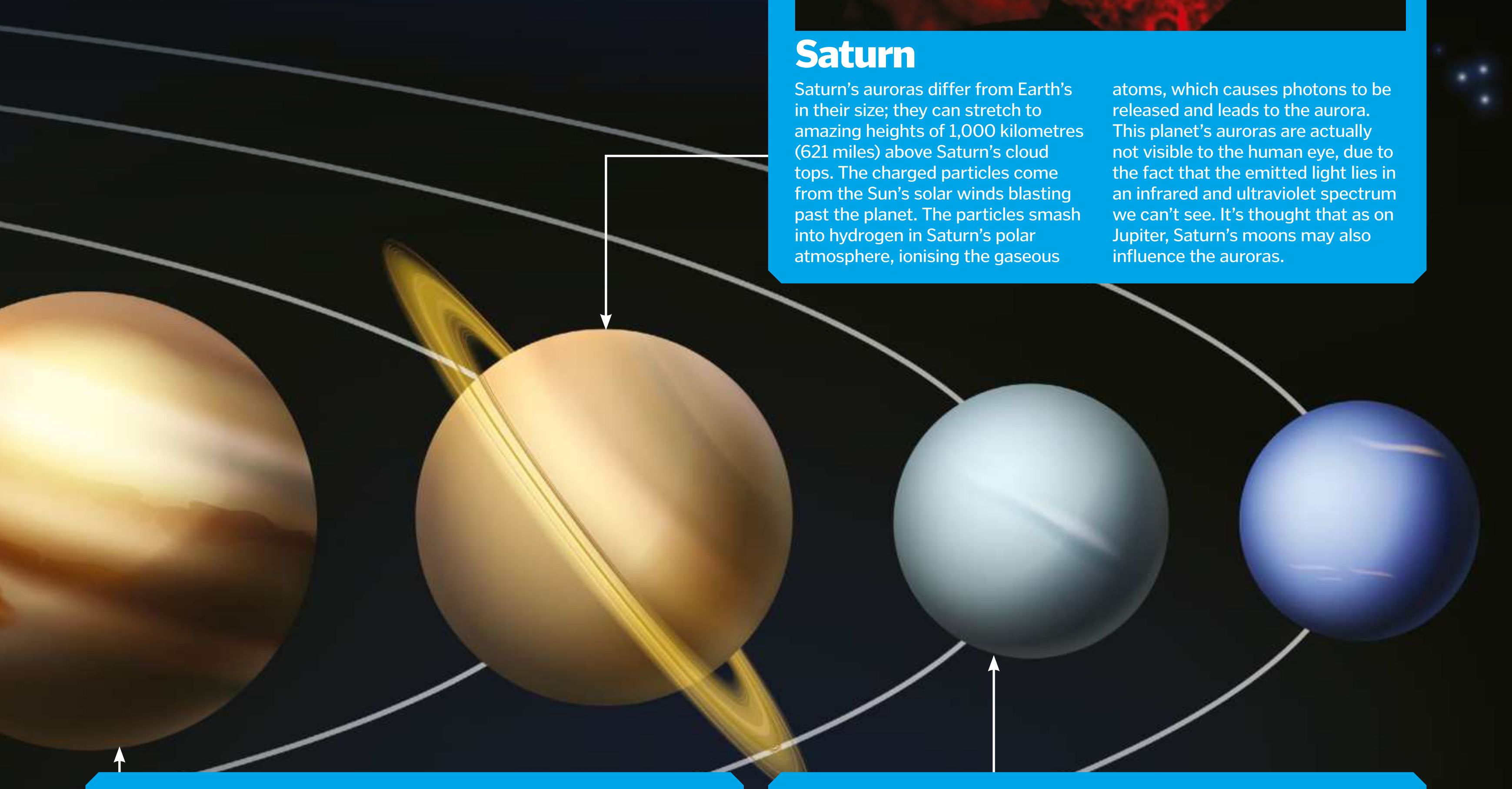


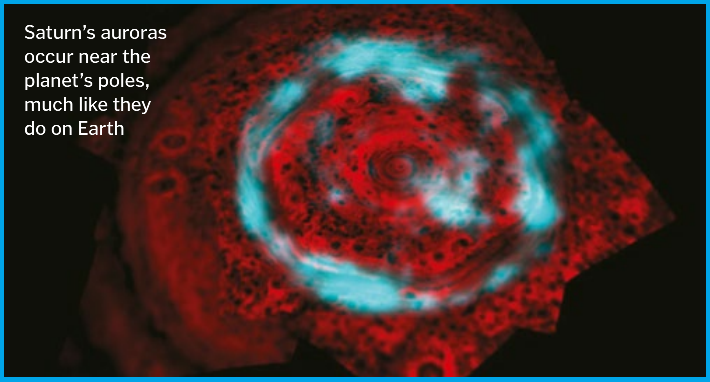
NASA's Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft observing the 'Christmas Lights Aurora' on Mars

Mars

On Mars, auroras appear near areas of magnetised rock within the planet's crust rather than near the poles, when charged solar particles concentrate toward them. This is because it lacks a self-generated magnetic field, possessing only 'crustal magnetic anomalies'. Scientists found that the location of the light emissions corresponded with the location of the strongest magnetic fields found on Mars. It is thought these anomalies are the last traces of Mars's planetary magnetic field, which it displayed at some time in its history. This type of aurora formation is totally unique to Mars as far as scientists are aware.

"On Jupiter, Saturn, Uranus and Neptune, auroras form in a similar manner to how they form on Earth"

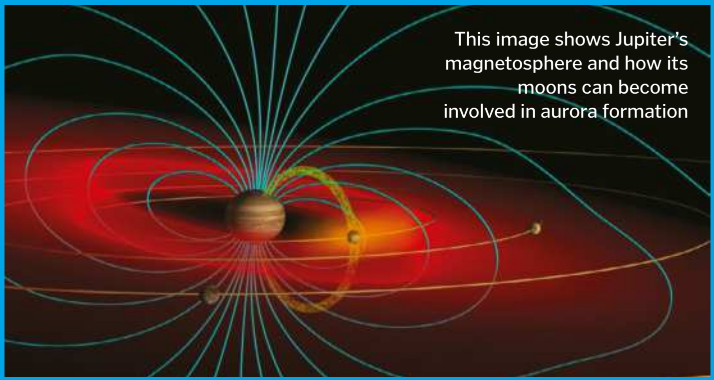




Saturn's auroras occur near the planet's poles, much like they do on Earth

Saturn

Saturn's auroras differ from Earth's in their size; they can stretch to amazing heights of 1,000 kilometres (621 miles) above Saturn's cloud tops. The charged particles come from the Sun's solar winds blasting past the planet. The particles smash into hydrogen in Saturn's polar atmosphere, ionising the gaseous atoms, which causes photons to be released and leads to the aurora. This planet's auroras are actually not visible to the human eye, due to the fact that the emitted light lies in an infrared and ultraviolet spectrum we can't see. It's thought that as on Jupiter, Saturn's moons may also influence the auroras.



This image shows Jupiter's magnetosphere and how its moons can become involved in aurora formation

Jupiter

Although some of the auroras found on Jupiter form in a similar manner to those on Earth, many are formed due to the trapping of particles within its own magnetic environment. Unlike Saturn's main aurora that changes size as the solar winds vary, Jupiter's main auroral ring maintains a constant size. This is due to its formation through interactions within its own magnetic environment. Jupiter's moons are also believed to be able to influence auroras. Io, Jupiter's volcanic moon, is thought to produce gases that travel into Jupiter's atmosphere, where they can contribute to the planet's aurora formation.

Uranus has a mass over 14 and a half times that of Earth's

Uranus

The presence of auroras on Uranus was detected in 2011 by the Hubble Space Telescope. It is thought this was possible due to heightened solar activity during this period, which increased the amount of charged particles carried in solar winds from the Sun. The auroras formed on this giant ice planet appear far away from the north and south poles, unlike on Earth. This is because of the planet's magnetic field, which is inclined at an angle of 59 degrees to the axis of its spin. These auroras are fainter than their Earth counterparts and last only a couple of minutes, unlike those on our planet, which may last for hours at a time.

The colours of the planets

Discover the science behind the colours in our Solar System

Of the eight planets in our Solar System, only two can't be seen unaided from Earth – Uranus and Neptune. And even then, unless you're observing through a telescope, the physical appearance of almost all planets will be difficult to perceive. Except of course Earth's neighbouring planet, Mars, which even ancient cultures correctly documented as being red, as its orange-red glow is distinguishable from Earth.

Space missions and scientific advancements in the last century have greatly improved our perception of the planets, including those closest and farthest away from the Sun. As a result we are now finally able to identify a planet's true colour and – more importantly – understand why it appears as such.

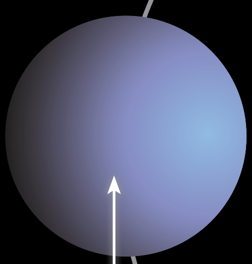
The colour of each planet is determined by what they made up of, and in some instances, how their atmospheres absorb and reflect light from the Sun.

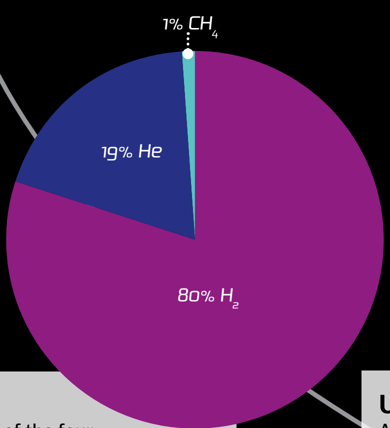
The four terrestrial planets, which have solid rock surfaces, are mostly grey or reddish-brown in appearance due to elements such as iron found on the surface. However, the surface of Venus is difficult to detect from space, as a dense atmosphere and thick clouds of acid surround it. The sulphur present in the clouds reflects the light and gives Venus its noticeable yellow colouring. A similar principle applies when it comes to determining the colours of the four gas giants. Uranus and Neptune, for example, appear to us as blue because methane gas present in their atmospheres absorbs red light, enabling them to only reflect blue.

Planetary colour palette

Here's how each planet is coloured, with each colour indicative of a certain element

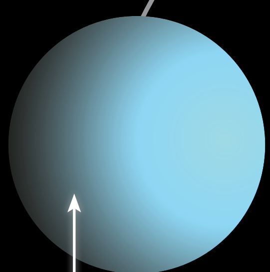
- **Hydrogen (H_2)**
- **Carbon dioxide (CO_2)**
- **Helium (He)**
- **Nitrogen (N_2)**
- **Oxygen (O_2)**
- **Methane (CH_4)**
- **Sodium (Na)**
- **Argon (Ar)**
- **Other gases (Oth)**

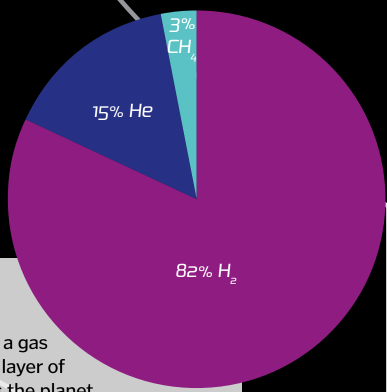




Neptune

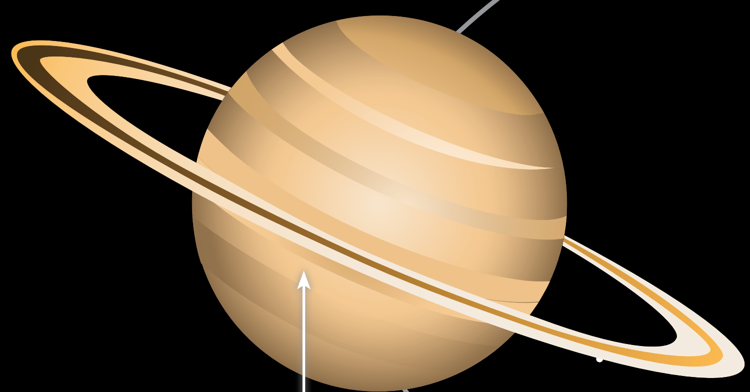
The smallest of the four gas giants, Neptune shares a lot of physical similarities with its neighbouring gas giant, Uranus, including its blue colouring. It's considered the windiest planet, with speeds recorded at around 2,414km/h (1,500mph). Extreme storms are also known to occur in its atmosphere and the planet also features a giant storm spot like Jupiter

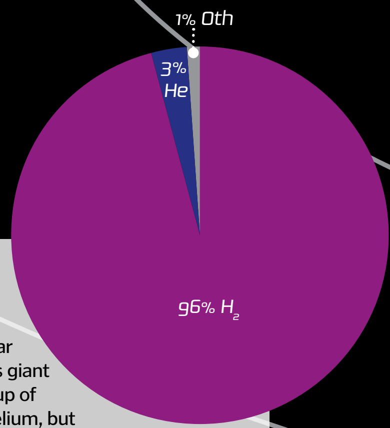




Uranus

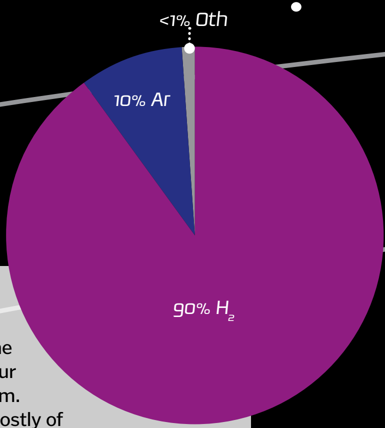
Although classified as a gas giant, an icy layer of cloud covers the planet Uranus. The coldest planet in our Solar System, temperatures at cloud level drop to below -220°C (-364°F). Methane in its atmosphere gives Uranus its distinct turquoise appearance; as red light is absorbed, only green-blue light is reflected





Saturn

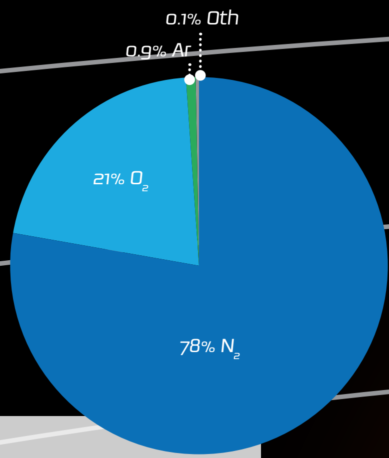
The lightest but second-largest planet in the Solar System. This gas giant is mostly made up of hydrogen and helium, but traces of ammonia, phosphine, water vapour and hydrocarbons in its atmosphere give the planet its distinct yellowish-brown colour. Saturn's famous rings, which are primarily made up of water ice, share a similar hue, but also vary in colour depending on density and the presence of other materials



Jupiter

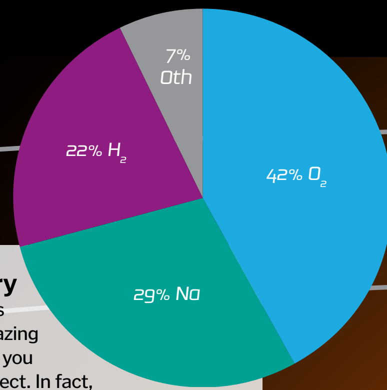
Gas giant

Jupiter is the largest in our Solar System. Made up mostly of hydrogen and helium, like the Sun, its structure resembles that of a star. Ice crystals and other elements help form thick bands of red, brown, yellow and white clouds, which encircle the entire planet. Its famous red spot can also be seen from Earth through telescopes



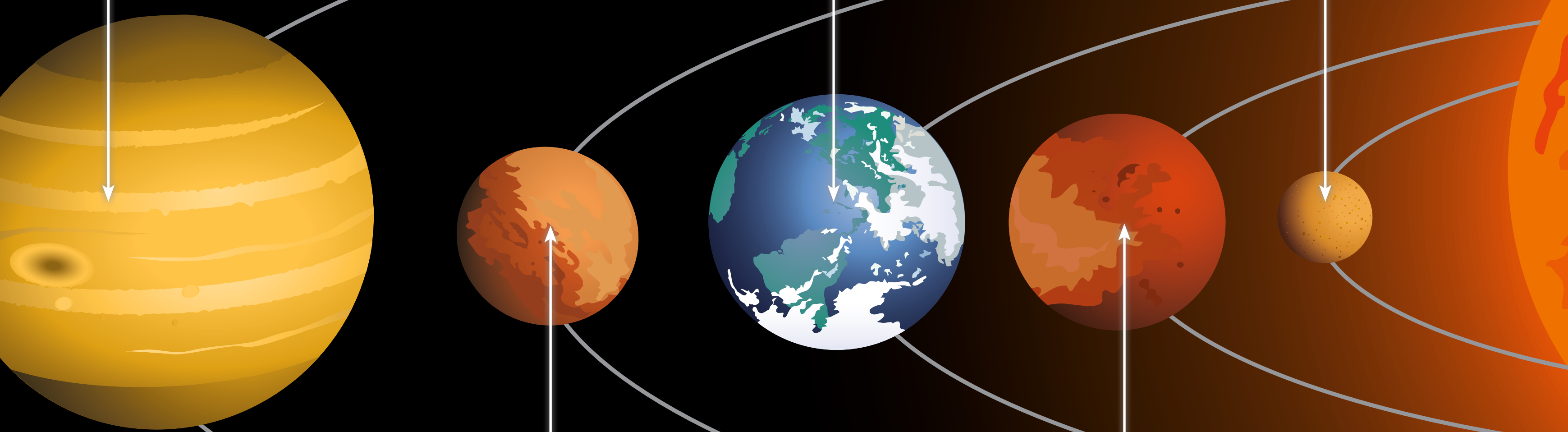
Earth

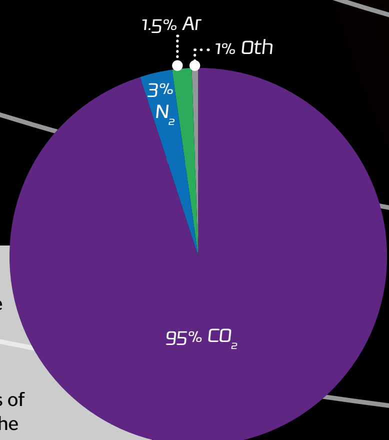
Earth is the only habitable planet in our Solar System, thanks to its unique atmosphere. It is also has liquid water on its surface, which is key to supporting life. From space you'll see vast blue oceans and green and brown land, as well as thick white cloud cover



Mercury

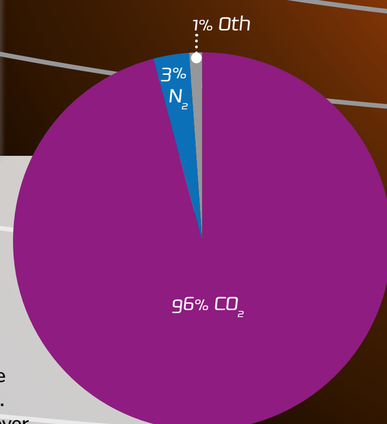
Mercury is not the blazing ball of fire you might expect. In fact, its appearance closely resembles Earth's Moon. Its cratered surface appears greyish-brown in colour due to the composition of its rocky surface, which is impacted by particles and solar winds. Temperatures fluctuate to extremes, thanks to its thin atmosphere





Mars

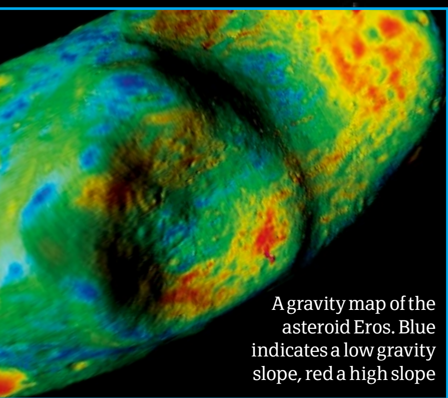
Mars is known as the Red Planet, so called because of its colouring, which is caused by high levels of iron oxide found on the surface. Although dry and dusty, temperatures on Mars are similar to those on Earth, but the planet is also plagued by powerful dust storms, a consequence of its thin atmosphere



Venus

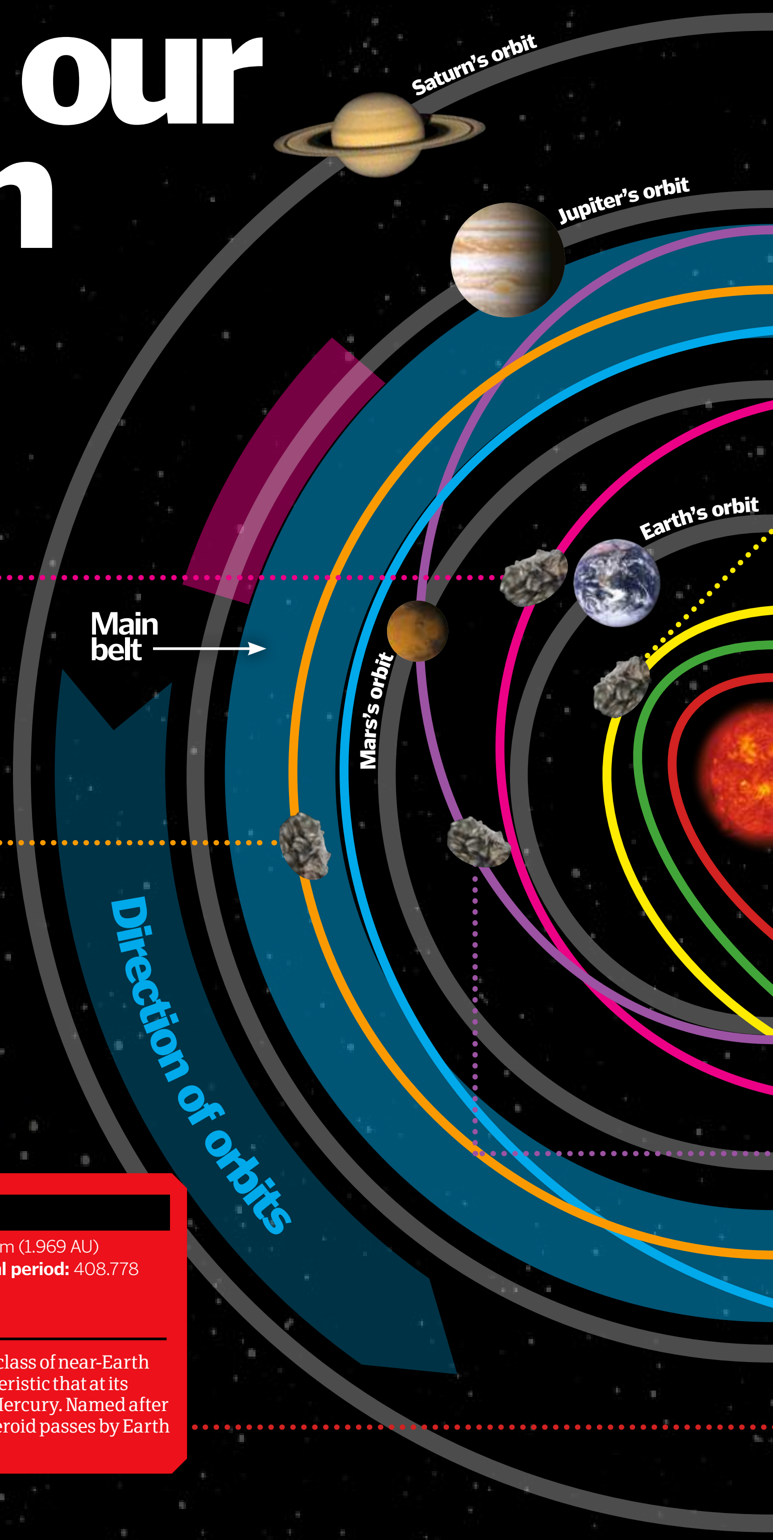
Volcanic activity has shaped the surface of Earth's largest neighbouring planet, Venus. Its dry, barren landscape is made up of greyish rock. From space, however, you'll notice thick, swirling yellow and white clouds, which are made up of sulphuric acid – a result of the planet's dense atmosphere

Asteroids in our Solar System



A gravity map of the asteroid Eros. Blue indicates a low gravity slope, red a high slope

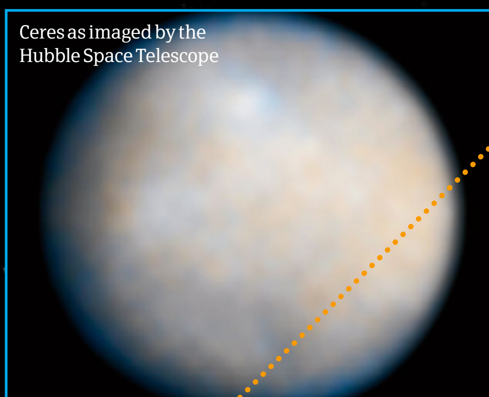
Most of the asteroids in our Solar System are positioned between the orbits of Mars and Jupiter, clustered in massive belts. However, some come close to Earth on their individual orbits and these are referred to as near-Earth asteroids. We take a look at some of the most notable…



Eros

Dimension: 16.84km
Aphelion: 266.762Gm (1.783 AU)
Perihelion: 169.548Gm (1.133 AU)
Orbital period: 643.219 days
Escape velocity: 0.0103km/s
Temperature: ~227K
Spectral type: S

With a one-in-ten chance of hitting either Earth or Mars in the next million years, Eros is one of the largest and well-studied near-Earth asteroids. In fact, Eros is one of a few asteroids to actually be landed upon by an Earth probe, and as such we have a cavalcade of information on it.



Ceres as imaged by the Hubble Space Telescope

Ceres

Dimension: 590 miles **Aphelion:** 446,669,320km (2.9858 AU) **Perihelion:** 380,995,855km (2.5468 AU) **Orbital period:** 1,680.5 days **Escape velocity:** 0.51km/s **Temperature:** ~167K **Spectral type:** C

Technically classed as a dwarf planet, Ceres – named after the Roman goddess of growing plants and the harvest – is by far the most massive body in the asteroid belt. Indeed, it is so big compared to its neighbouring asteroids that it contains 32 per cent of the belt's total mass.

Icarus

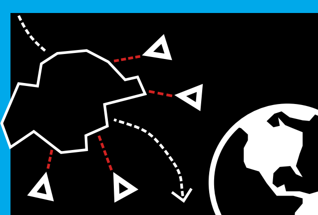
Dimension: 1.4km **Aphelion:** 294.590Gm (1.969 AU) **Perihelion:** 27.923Gm (0.187 AU) **Orbital period:** 408.778 days **Escape velocity:** 0.000 74 km/s **Temperature:** ~242K **Spectral type:** U

Icarus is from the Apollo asteroid sub-class of near-Earth asteroids and has the unusual characteristic that at its perihelion it is closer to the Sun than Mercury. Named after the Icarus of Greek mythology, the asteroid passes by Earth at gaps of nine, 19 and 38 years.

How to deflect an impact…

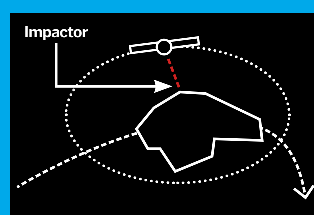
1. Nuclear explosions

This method involves firing a nuclear bomb into the asteroid. Problems may occur if the explosion just splits the asteroid into smaller pieces.



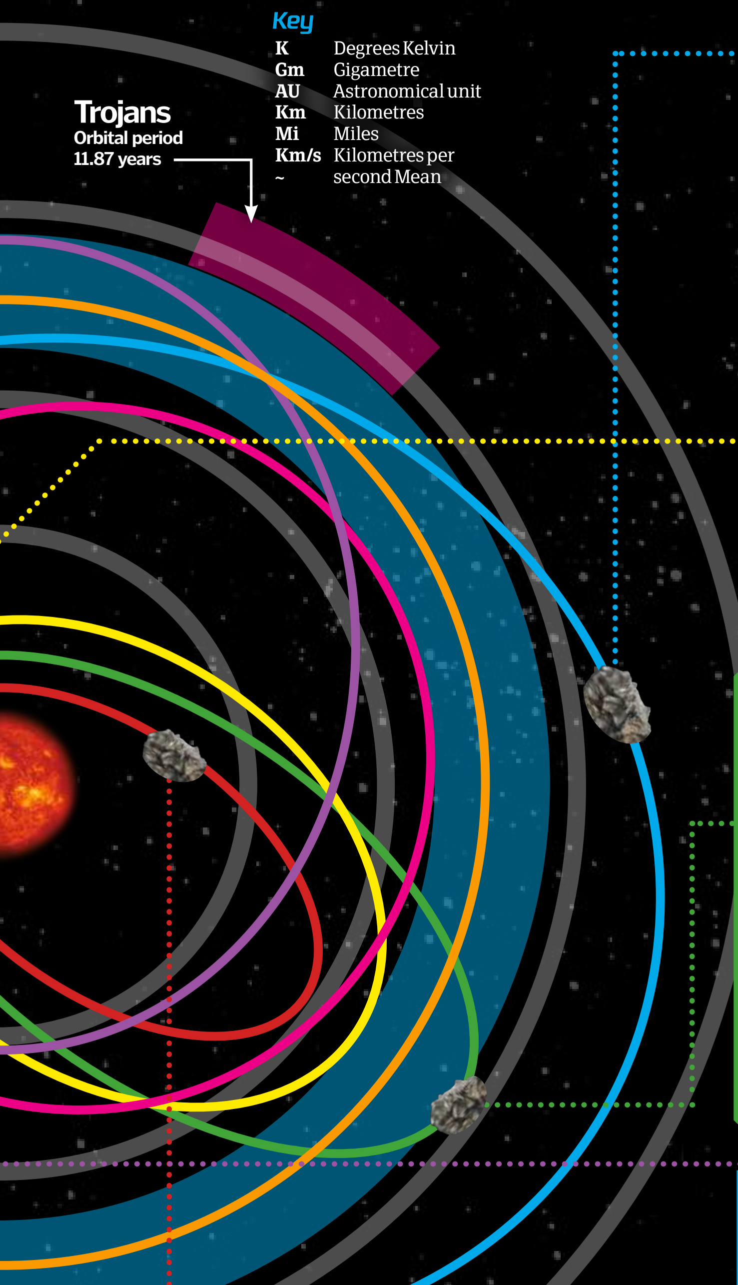
2. Multiple explosions

Detonating multiple nuclear bombs close to impact would push the asteroid to one side and onto another, non-Earth destroying trajectory.



3. Kinetic impactor

Similar to the last option, this method would involve firing a solid projectile into an asteroid in order to alter its momentum and change its course.



Hidalgo

Dimension: 38km **Aphelion:** 1427.003Gm (9.539 AU) **Perihelion:** 291.846Gm (1.951 AU) **Orbital period:** 5,029.467 days **Escape velocity:** 0.011km/s **Temperature:** ~116K **Spectral type:** D

Hidalgo has the longest orbital period of any asteroid outside of the traditional asteroid belt, with a full orbit taking over 13 years. Hidalgo grazes Saturn's orbit at its aphelion and its severe orbital inclination (43°) is thought to be the result of a close encounter with Jupiter.

Apollo

Dimension: 1.7km **Aphelion:** 343.216Gm (2.294 AU) **Perihelion:** 96.850Gm (0.647 AU) **Orbital period:** 651.543 days **Escape velocity:** 0.0009km/s **Temperature:** ~222K **Spectral type:** Q

Apollo is a Q-type (metal-rich) asteroid discovered in 1932 that was then lost until 1973. Named after the god of light and Sun in Greek mythology, Apollo shares its name with the Apollo sub-class of near-Earth asteroids. Apollo was the first asteroid recognised to cross Earth's orbit.

Adonis

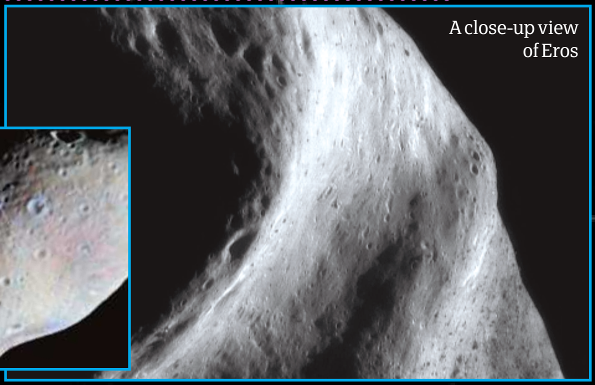
Dimension: 0.5-1.2km
Aphelion: 494.673Gm (3.307 AU)
Perihelion: 65.906Gm (0.441 AU)
Orbital period: 936.742 days
Escape velocity: 0.0003-0.0006km/s
Temperature: 197-207K
Spectral type: C

Adonis was the second asteroid to be discovered in the Apollo sub-class of asteroids, found in 1936. It is named after the Adonis of Greek mythology, it closely passes Venus on its orbit. Adonis will make close approaches to Earth six times during the 21st century.

Amor

Dimension: 1.5km
Aphelion: 412.011Gm (2.754 AU)
Perihelion: 162.403Gm (1.086 AU)
Orbital period: 971.635 days
Escape velocity: 0.000 79km/s
Temperature: ~198K
Spectral type: C/S

As with Apollo, Amor shares its name with the Amor sub-class of near-Earth asteroids, a group that approach the orbit of the Earth from beyond but never cross it. Eugéne Delporte discovered the asteroid in 1932, when it was imaged as it approached Earth to within 16 million kilometres.


A close-up view of Eros

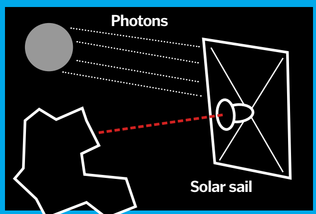

The asteroid Gaspra

Filling the gap

Franz Xaver von Zach (1754-1832), astronomer and leader of the Seeberg Observatory, Germany, believed that there was a missing planet orbiting the Sun between Mars and Jupiter. To prove his theory von Zach organised a group of 24 astronomers and gave them each a part of the celestial zodiac to search in an attempt to track down his errant planet. Unfortunately, despite such a large team, von Zach was beaten to the discovery by the Italian Catholic priest and mathematician Giuseppe Piazzi, who accidentally discovered the asteroid Ceres in 1801.

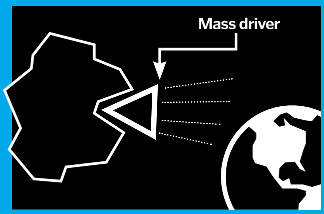

Franz Xaver Von Zach


Giuseppe Piazzi



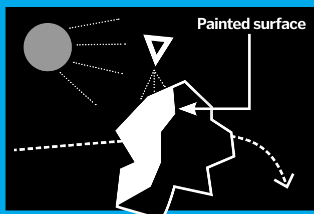
4. Solar sail

This method would involve attaching a 5,000km-wide sail to an asteroid. The constant pressure of sunlight over a large area would slowly alter its course.



5. Mass driver

A huge space drill would be fired into the asteroid, and drill out the innards before firing them into space, altering its mass and changing the course.

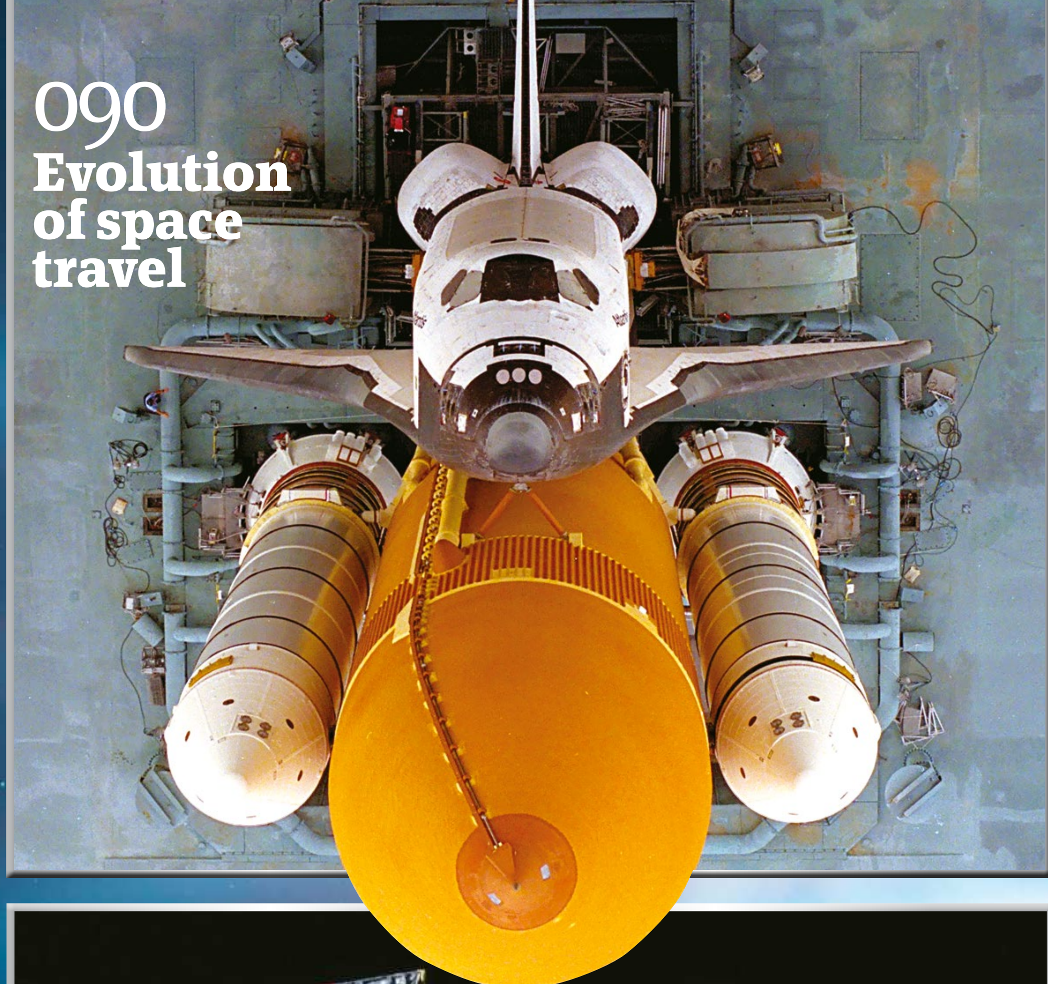


6. Paint

By coating parts of the asteroid in paint, the amounts of thermal radiation emitted by the asteroid's Sun-facing side could be increased, altering its path.

EXPLORATION

086
Space tourism



"There will be plenty of adventurers packing their bags for trips to space"

Alien Earths

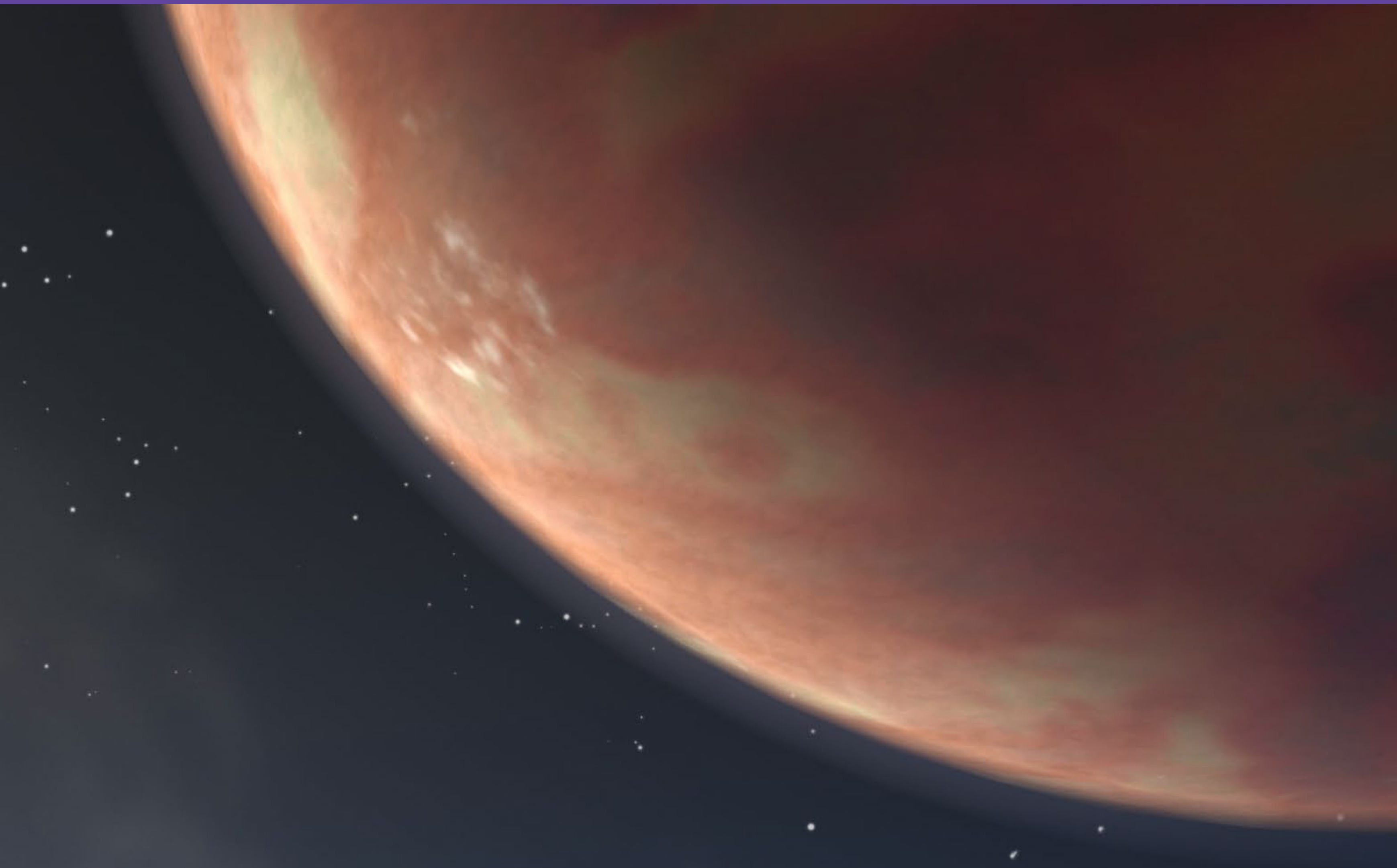
Discover the five strangest exoplanets ever found

To boldly go – in *Star Trek* the starship Enterprise would visit new planets every week from the Sixties onwards, but until 1995 we didn't even know whether planets around normal stars existed. Then astronomers found the first hot Jupiter, called 51 Pegasi b, which is a gas giant like our Jupiter, but extremely close to its star. That discovery opened the floodgates and today we know of over 1800 confirmed planets of all types – large and small, hot and cold, gas and ice.

To differentiate them from the planets of our familiar Solar System home, astronomers call these alien worlds extra-solar planets, or exoplanets for short. Of all these planets, less than two dozen have actually been photographed (and in the pictures they are just points of light). The others are detected through several methods, the two dominant ones called the radial velocity technique and the transit method. The former makes use of the gravitational interaction between a star and a planet – the star orbits the centre of mass between the star and planet, and so to us it appears to wobble, sometimes by just a few centimetres, but this causes its light to be Doppler shifted. The size of the Doppler shift and the period of the wobble tells us about the mass of the orbiting exoplanet and the size of its orbit.

Transits happen when a planet passes in front of its star. Our telescopes are not powerful enough to resolve the silhouette of the planet in front of its star, but we can detect the tiny dip in the star's light. The size of the dip, and the regularity with which the transits happen tell us the diameter of the planet and how far from its star it is. If astronomers are able to see a transit and measure the radial velocity, they can then measure both the mass and diameter of the planet, and calculate its density and work out whether it is rocky, gaseous or some mixture of the two.

Exoplanets are discovered with both ground-based telescopes and space-based telescopes, like the Kepler planet-finding satellite, and with a new wave of planet-finding space missions being built, as well as giant ground-based telescopes, we can expect to discover thousands more planets, and perhaps even a planet just like Earth.



Exoplanet most like Earth

One of the great quests is to find a planet that is like Earth and could support life. Astronomers tend to categorise these planets as being found in the habitable zone, where temperatures are just right for liquid water on the surface. The best candidate so far is GJ 667Cc, which orbits a red dwarf in a triple star system. It is a super-earth, nearly four times the mass, and would be slightly hotter than Earth. It is unknown whether there is alien life.

The statistics...

GJ 667Cc

Distance: 22.7 light years

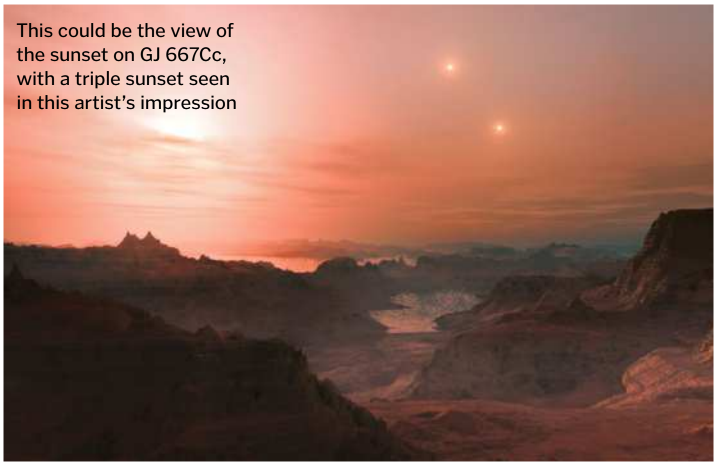
Mass: 2.26 x 10^{25} kg (3.78 Earth masses)

Diameter: 22,425km

Length of year (orbital period): 28 Earth days

Discovered: 2012

Discovery method: Radial velocity



This could be the view of the sunset on GJ 667Cc, with a triple sunset seen in this artist's impression

The planet-sized hurricane

The strongest winds ever measured on Earth was 408kph (253mph), but this was just a breeze compared to the winds measured on HD 80606b, which reach 10800mph (17380kph)! The reason for these winds is the planet's egg-shaped orbit, which at times brings it just 4.5 million km (2.8 million miles) from the Sun. This causes the atmosphere to heat up rapidly each time it comes close. This heat drives a superstorm in its atmosphere.

The statistics...

HD 80606b

Distance: 190 light years

Mass: 7.6 x 10^27kg (4 Jupiter masses)

Diameter: 128,776km

Length of year (orbital period): 111 Earth days

Discovered: 2001

Discovery method: Radial velocity

Hot Jupiters like HD 80606b can come incredibly close to their stars, the heat driving powerful winds

The planet from hell

What happens when a rocky planet finds itself in a similar situation to a hot Jupiter? CoRoT-7b is a molten world with a temperature between 1800 and 2600 degrees Celsius on its sun-facing side. It is tidally locked, so it always shows the same face to its star like the Moon does to Earth. The dayside's surface will be an ocean of lava, while the gravity from the nearby star will flex the planet's interior, causing the farside to be covered in giant volcanoes.

The statistics...

CoRoT-7b

Distance: 489 light years

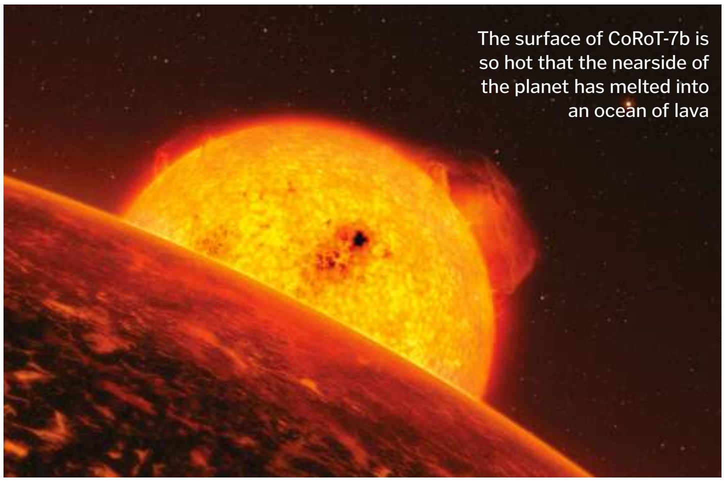
Mass: 5-9 times the mass of Earth

Diameter: 20,132km

Length of year (orbital period): 20 hours

Discovered: 2009

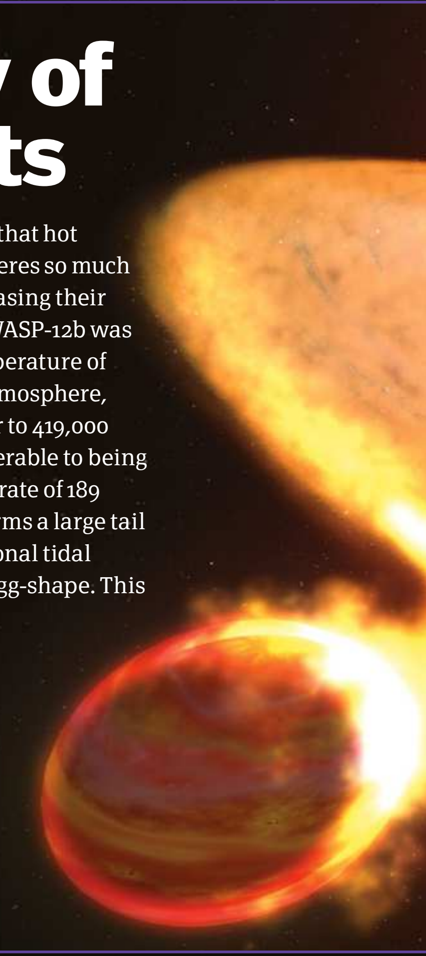
Discovery method: Transit



The surface of CoRoT-7b is so hot that the nearside of the planet has melted into an ocean of lava

Big daddy of the planets

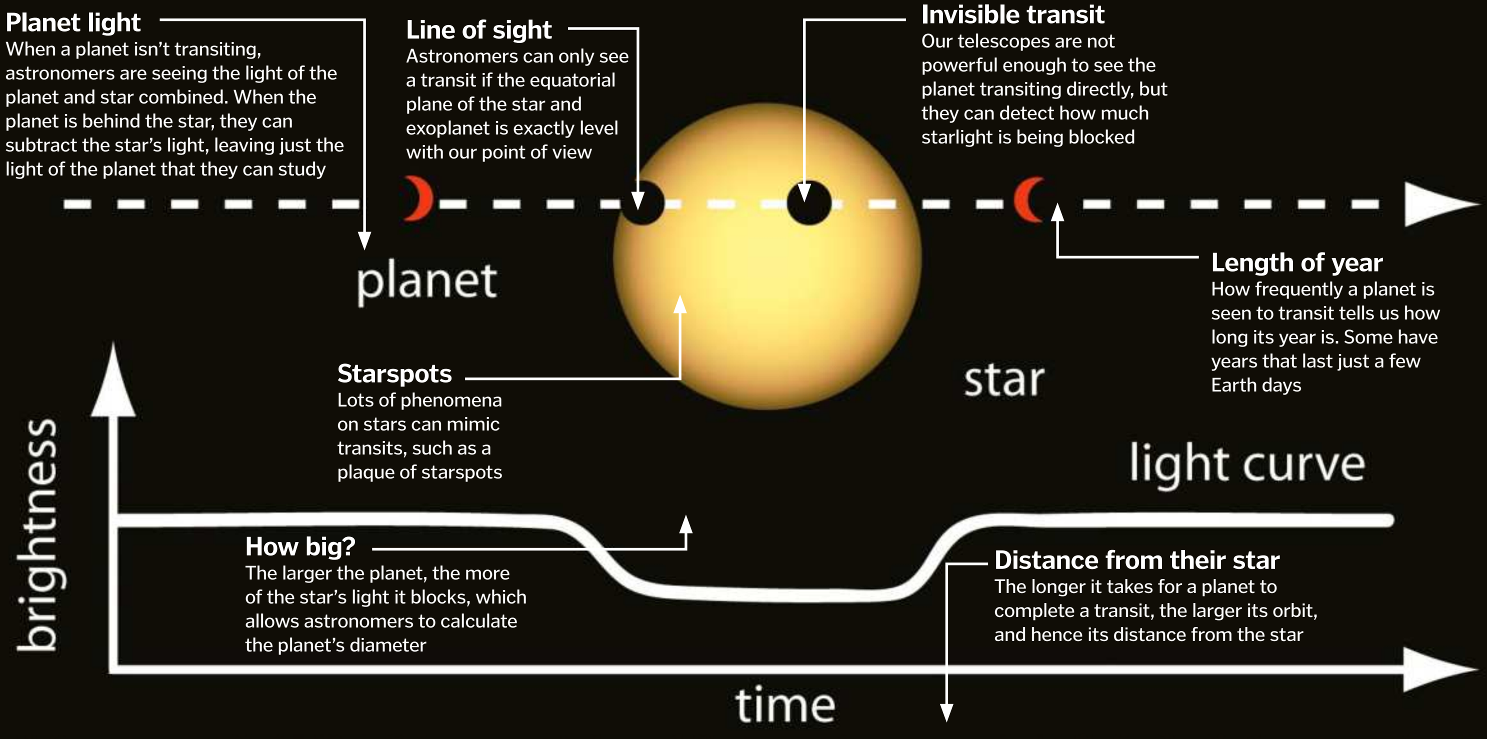
Besides the powerful winds, the heat that hot Jupiters receive warms their atmospheres so much that their atmospheres expand, increasing their diameters. When it was discovered, WASP-12b was the hottest planet known, with a temperature of 2250 degrees Celsius. Its expanding atmosphere, which increases the planet's diameter to 419,000 kilometres (257 million miles), is vulnerable to being torn away by the gravity of its sun at a rate of 189 quadrillion tonnes per year, which forms a large tail of gas, a bit like a comet. The gravitational tidal forces also distort the planet into an egg-shape. This is one very messed-up planet.



WASP-12b's expanded atmosphere is being torn away into a long tail that forms a disk around its star

Understanding exoplanet transits

The Kepler Space Telescope discovers planets by watching for their transits as they pass in front of their stars.



"Its expanding atmosphere, which increases the planet's diameter to 419,000km, is torn away by its sun's gravity"

The statistics...

WASP-12b

Distance: 800 light years

Mass: 2.56 x 10^{27} (1.3 times mass of Jupiter)

Diameter: 255870km

Length of year (orbital period): 26 hours

Discovered: 2008

Discovery method: Radial velocity

A diamond in the rough

Astronomers tend to focus on the surfaces, or cloud tops of planets, but sometimes what lies beneath is even more interesting. The planet known as 55 Cancri e is a huge 'super-Earth'. It is dry, with no chemical signature of water, and it is rich in carbon, amounting to a third of the planet's mass. In its core, all this carbon will be compressed under high pressures, to the point that deep within 55 Cancri e there is quite possibly a giant core of diamond.

The statistics...

55 Cancri e

Distance: 41 light years

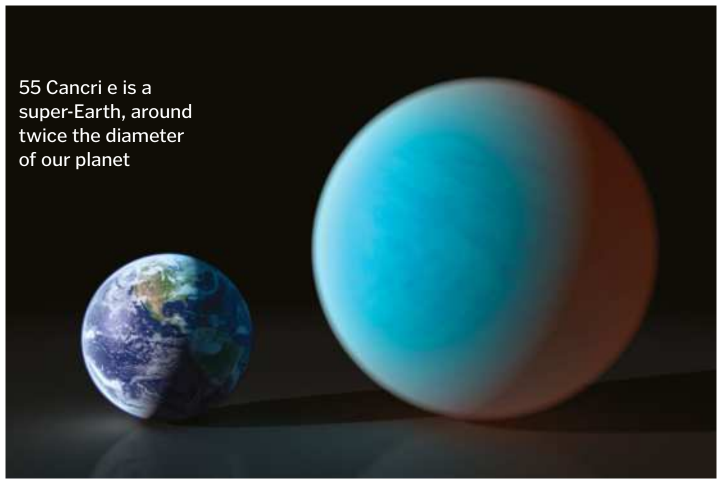
Mass: 4.7 x 10^{25}kg (7.8 Earth masses)

Diameter: 24,000km

Length of year (orbital period): 17 hours

Discovered: 2004

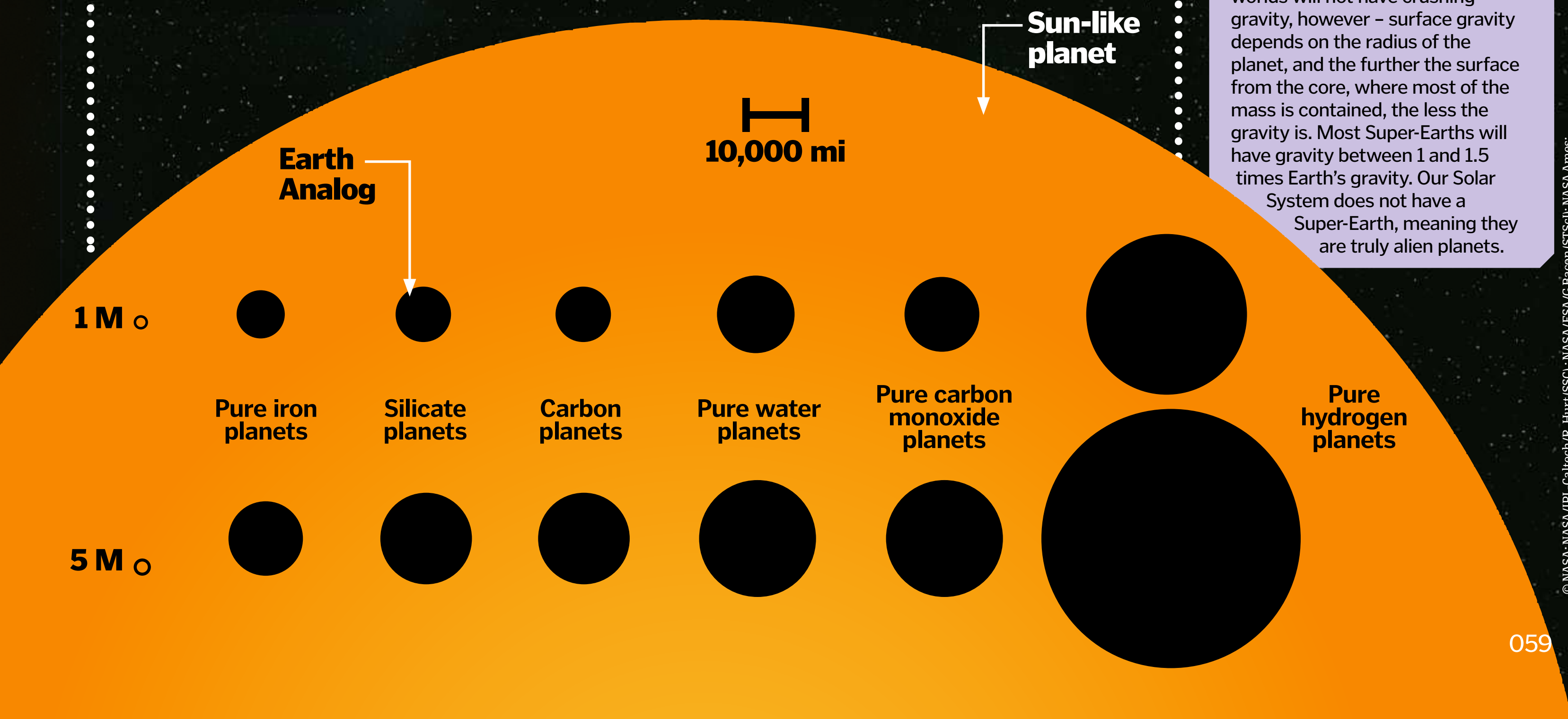
Discovery method: Radial velocity



55 Cancri e is a super-Earth, around twice the diameter of our planet

Predicting the sizes of exoplanets

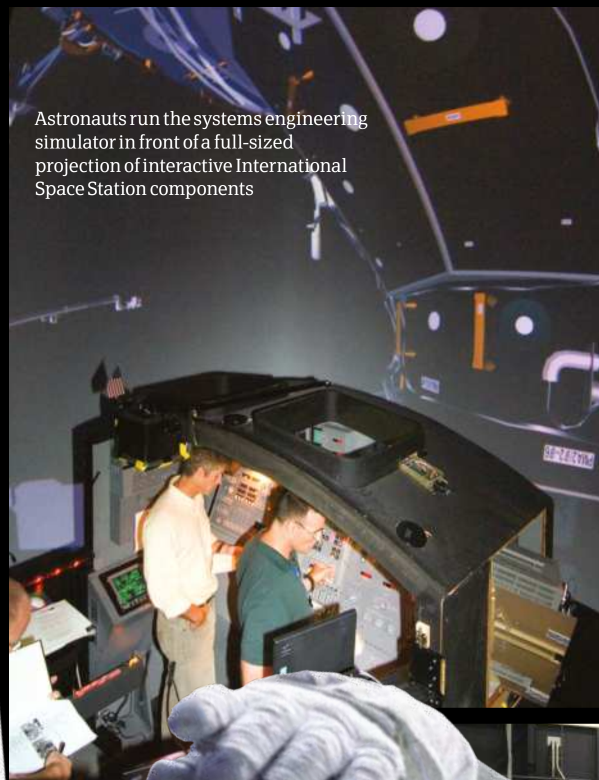
The size of a transit – in other words, how much star light is blocked – tells astronomers how big the planet transiting is. This doesn't tell us its mass or what it is made from though, but we can work out its volume from its diameter. We can learn its mass by seeing how much its gravity causes its star to 'wobble'. Density is calculated by dividing the planet's mass by its volume, and knowing the density astronomers can figure out whether the planet is made of rock, gas or water.



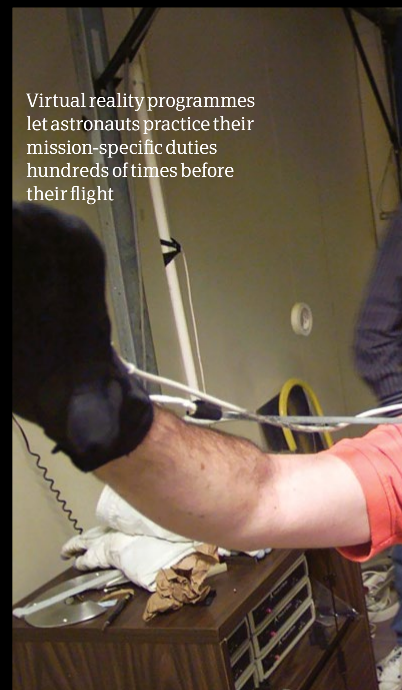
Giant Super Earths

Super-Earths are rocky planets like Earth or Mars, but much, much bigger. They can be up to ten times the mass of our planet! These worlds will not have crushing gravity, however – surface gravity depends on the radius of the planet, and the further the surface from the core, where most of the mass is contained, the less the gravity is. Most Super-Earths will have gravity between 1 and 1.5 times Earth's gravity. Our Solar System does not have a Super-Earth, meaning they are truly alien planets.

If you think you have what it takes to be an astronaut, think again...



Astronauts run the systems engineering simulator in front of a full-sized projection of interactive International Space Station components



Virtual reality programmes let astronauts practice their mission-specific duties hundreds of times before their flight

Engineers test a new extra-vehicular space suit with a partial gravity simulator

Astronaut training

It's now been over 60 years since Russian cosmonaut Yuri Gagarin became the first man in space, but with the rare exception of a few billionaire civilians, space travel is still a well-guarded privilege.

As NASA initiates a new long-term mission to return to the Moon and push on to Mars, the space agency is looking for a few good men and women who contain the rare mix of hyper-intelligence, marathon stamina and good old-fashioned guts to board the brand-new Ares I-X rocket and blast off to the uncharted depths. What does it take to become one of the lucky few to venture into space?

This huge centrifuge doesn't test the g-force limits of astronauts, but replicates up to 3.5g for flight simulation exercises

American and Russian astronauts train for spacewalks in the massive Hydrolab at the Gagarin Cosmonaut Training Center

NASA basic training

NASA astronaut training is much like cramming for final exams at MIT while simultaneously enduring basic training for the Green Berets. Candidates begin their training in the classroom, taking advanced courses in astronomy, physics, mathematics, geology, meteorology and introductions to the Space Shuttle guidance and navigation systems. Sorry, no poetry electives.

Both pilots and non-pilots are trained to fly T-38 jets, highly acrobatic aircrafts that can reach 50,000ft. Pilots must log 15 hours of flight time a month, plus extra practice landing the Shuttle Training Aircraft (100 more hours). Non-pilots must log a minimum of four hours a month in the T-38.

But before astronaut candidates even step foot in a flight simulator, they need to be trained in military water survival. That means scuba certification and the proven ability to swim three lengths of an Olympic size pool in full flight gear and shoes. To cover all contingencies, astronaut candidates are also trained in wilderness survival, learning how to navigate by the stars and to live on nuts and berries.

The torture isn't over yet. To weed out the weaklings, candidates are subjected to extremes of high and low pressure and trained to deal with the 'consequences'. Then they're taken for a joyride in the infamous KC-135, aka 'the weightless wonder', aka 'the vomit comet', to experience 20-second shots of weightlessness. Some people love it, some people are violently sick.

After that it's time to brush up on a couple dozen equipment manuals in preparation for intense training with full-size, fully functional simulators, everything from flight controls to hydraulic arms, even down to how to use the toilet. Every single astronaut candidate is trained in every phase of space flight, ranging from pre-launch diagnostics to emergency landing procedures.

Candidates also train in the Johnson Space Center's Neutral Buoyancy Laboratory, an immense pool that faithfully simulates near-weightlessness. Here, they prepare for both the extraordinary and mundane aspects of space life. They conduct underwater 'space walks' in full space gear and practice making freeze-dried snacks in the tiny Shuttle kitchen.

Finally comes the mission-specific training, where each member of the team runs countless simulations within his or her area of expertise. Scientists conduct their experiments over and over. Engineers do hundreds of mock space walks to make repairs to space station components. And pilots pretty much live in the flight simulators. After two years of full-time training, the candidates receive a silver lapel pin indicating they are officially astronauts. After their first flight, it's swapped for a gold one.

This centrifuge is designed to test the effects of linear acceleration on visual function in space

So you want to be an astronaut?

In the late Fifties, when NASA began its internal search for the first seven astronauts, it drew from the ranks of the most experienced Air Force pilots. A lot has changed since the dawn of space flight, and so have the résumés of modern astronauts.

There are still some military pilots in the ranks, but they're in the minority. Today's astronauts are more likely to be academics, scientists and engineers of all stripes – particularly astronautical engineers.

Astronaut candidates are chosen through a rigorous application process and there is no career path that guarantees admission into the programme, although many current astronauts work for years within the NASA research and development ranks before suiting up themselves.

HEAD 2 HEAD

THE YOUNGEST, OLDEST AND MOST EXPERIENCED ASTRONAUTS IN HISTORY

YOUNGEST

1. Gherman Stepanovich Titov

Age: 25

Facts: Only the second man in space after Yuri Gagarin, this charismatic young Russian cosmonaut was the first to make multiple orbits (17, in fact) of the Earth on 6 August 1961. He is probably most famous for his in-flight exuberance, repeatedly calling out his codename: "I am Eagle! I am Eagle!"

OLDEST

2. John Glenn

Age: 77

Facts: On 20 February 1962, John Glenn piloted NASA's very first manned orbital mission of the Earth, whipping around the globe three times in under five hours. Fast forward 36 years to 29 October 1998, when the retired US senator took his second space flight, a nine-day mission exploring – among other things – the effects of space flight on the aging process.

MOST TIME IN SPACE

3. Gennady Padalka

Total duration: 878 days

Facts: RKA Cosmonaut Padalka crushes all competitors in the category of most time spent in space. He flew five missions between 1998 and 2015, notching up over two years in space. Having spent 878 days in space in total, Padalka resigned from the Russian space programme in 2017, citing the decreasing likelihood of his being able to go into space again as his reason for leaving the programme.

Inside a spacesuit

What's so special about an astronaut's outfit that it can keep them alive in space?

It's probably best to think of a spacesuit not as an item of clothing – like a jumper you'd put on when it's cold or a pair of wellies to keep your feet dry – but as a habitat or a small personal spaceship that astronauts wear when they're out in space.

Two of the main threats to human life in space are the lack of oxygen and the extreme range of temperatures, which can fluctuate from below -100 degrees Celsius (-150 degrees Fahrenheit) to in excess of 120 degrees Celsius (242 degrees Fahrenheit). But they can face other dangers, too: the extremely low pressure, micrometeorites travelling several times the speed of a bullet and exposure to high levels of radiation, unfiltered by any planetary atmosphere like Earth's, travelling from the Sun and deep space.

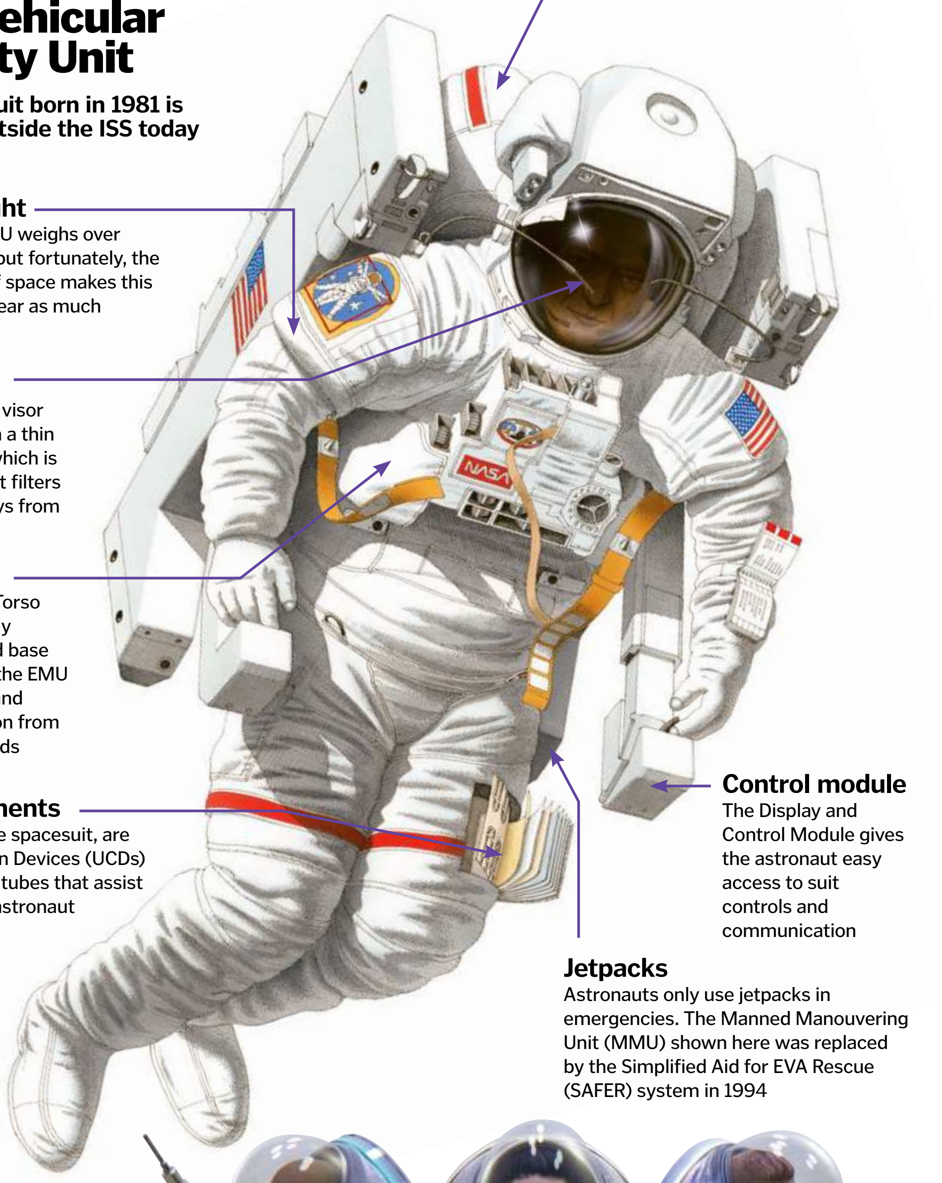
Astronauts need protection from these dangers while on an extravehicular activity in space, so the modern spacesuit is designed to do just that. The outer section is divided into several main pieces with flexible and rigid parts, designed to provide mechanical protection from impact and a pressurised, oxygenated environment within the suit.

Underneath that, the astronaut wears a garment that helps regulate their body temperature with tubes that are woven into it, inside which water circulates for cooling. The astronaut's chunky backpack carries the primary life support subsystem, which pumps the oxygen into the astronaut's helmet for them to breathe and 'scrubs' the excess carbon dioxide out of the air they exhale. It also holds the electricity supply required to run the suit's systems and a water tank for the cooling system.

"The astronaut's backpack carries the primary life support subsystem..."

Extravehicular Mobility Unit

The space suit born in 1981 is still used outside the ISS today



Life support
The heavy backpack contains power for the spacesuit, air and a water tank for cooling

Heavyweight
A complete EMU weighs over 100kg (220lb) but fortunately, the microgravity of space makes this feel nowhere near as much

Gold layer
An astronaut's visor is covered with a thin layer of gold, which is transparent but filters out harmful rays from the Sun

Protection
A Hard Upper Torso (HUT) assembly provides a rigid base for the rest of the EMU to connect to and some protection from micrometeoroids

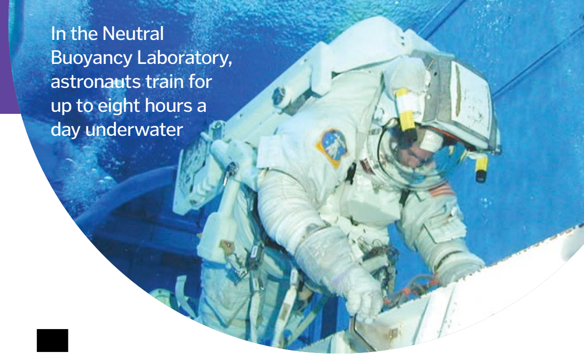
Undergarments
Underneath the spacesuit, are Urine Collection Devices (UCDs) and a series of tubes that assist in cooling the astronaut

Control module
The Display and Control Module gives the astronaut easy access to suit controls and communication

Jetpacks
Astronauts only use jetpacks in emergencies. The Manned Manouvering Unit (MMU) shown here was replaced by the Simplified Aid for EVA Rescue (SAFER) system in 1994

The Z2-suit

NASA's prototype Z2-suit is currently still a work in progress on an update to the current incarnation of the spacesuit, whose basic structure has been used for over 40 years, ever since the Extravehicular Mobility Unit (EMU) was first made in 1981. At a glance, it doesn't look like it is radically different to our contemporary space suits, but it's actually been designed to include several new key features that will allow it to be used in both the microgravity of space and also for future missions to planets such as Mars, which the Apollo-era spacesuit isn't actually capable of. It can be quickly put on and taken off (current spacesuits can take an hour or more to put on) and include a suitport dock, which replaces the airlock on a spacecraft. This means that the spacecraft and space suit would be kept at the same pressure, so astronauts wouldn't need to pre-breathe oxygen for at least 30 minutes before an EVA as they do now in order to prevent decompression sickness.



In the Neutral Buoyancy Laboratory, astronauts train for up to eight hours a day underwater

Underwater astronaut training

The best place on Earth to prepare for zero gravity is a swimming pool

When an astronaut prepares for a mission to the International Space Station, they must practise the tasks that they'll be carrying out in space. However, in order to make the training as realistic as possible, the microgravity they'll encounter outside our planet's atmosphere needs to be mimicked here on Earth.

It may sound far-fetched, but NASA has an ingenious way of replicating space's unique environment on our home planet – it has placed a large-scale mock-up of the International Space Station in an enormous swimming pool. The American space agency calls this 12-metre (40-foot) deep pool the Neutral Buoyancy Lab (NBL) and astronauts have been training here since 1996.

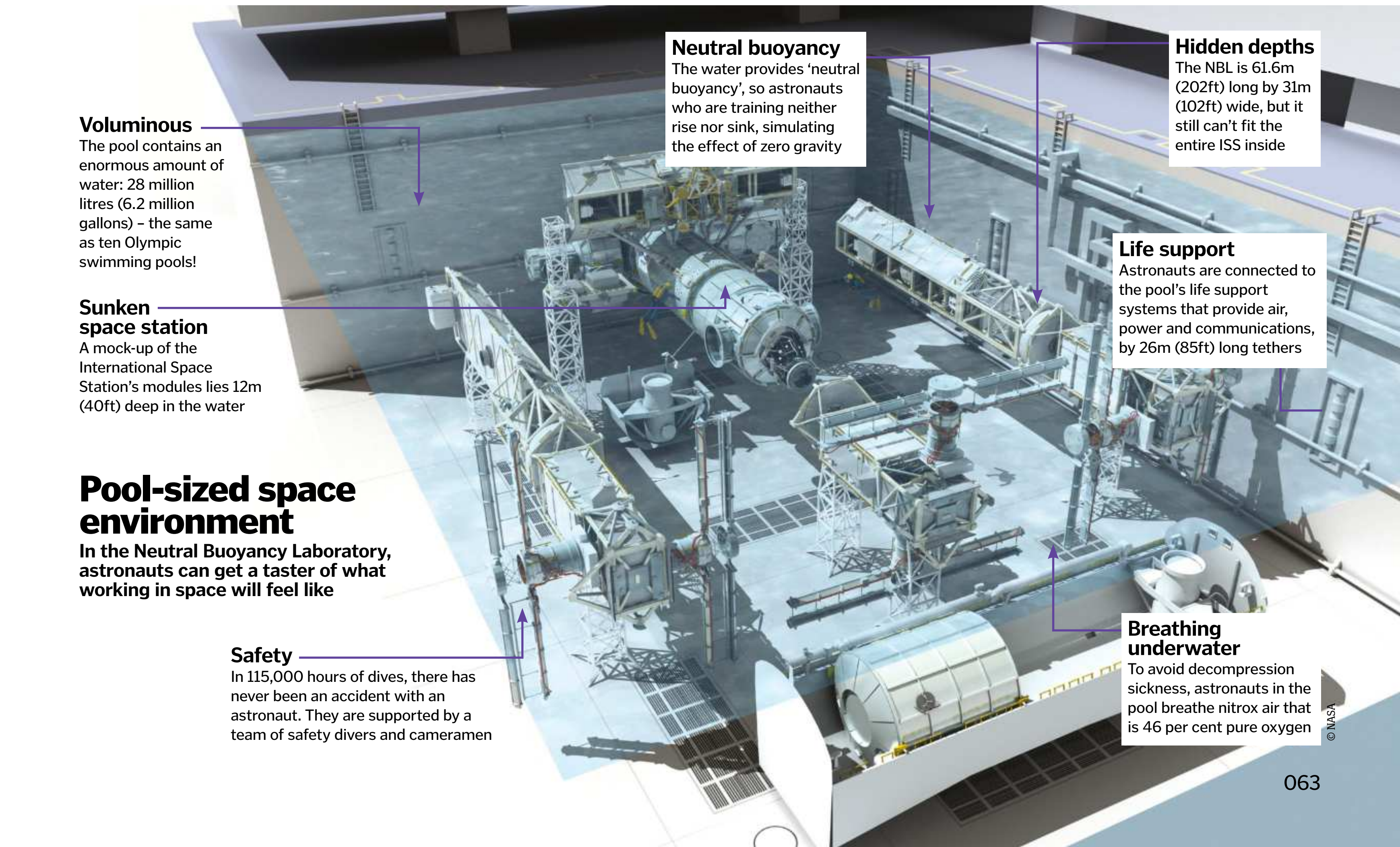
Astronauts undertake six-to-eight-hour underwater sessions on a daily basis – the equivalent time for an Extravehicular Activity session in space. When it's time to begin training, a camera diver shadows the astronaut to capture everything that happens, so it can be reviewed later. Safety divers are also on-hand at all times and the astronaut is rigged up to various support systems for air, power and communications.

Underwater, the trainee astronaut is breathing nitrox air, which is comprised of 46 per cent oxygen rather than the normal 21 per cent we breathe every day. This increased oxygen concentration reduces the risk of decompression sickness. Long tethers also enable an astronaut to lock themselves onto handrails while they are practising a task. Everything they do underwater is a simulation of what they'll be doing onboard the International Space Station.

Size does matter

Before getting in the water for a session in the Neutral Buoyancy Laboratory, an astronaut has to dress for the part. During the fitting for their space suit, there are 36 measurements taken of their bodies and 46 measurements of their hands, while plenty of padding inside the suit ensures they don't slip around. The end result is so heavy – weighing almost as much as two men – that several technicians are required to help the astronaut get suited and booted.

European Space Agency astronaut Samantha Cristoforetti, flight engineer of Expedition 42/43, prepares to be submerged in the waters of the NBL



Pool-sized space environment

In the Neutral Buoyancy Laboratory, astronauts can get a taster of what working in space will feel like

Voluminous
The pool contains an enormous amount of water: 28 million litres (6.2 million gallons) – the same as ten Olympic swimming pools!

Sunken space station
A mock-up of the International Space Station's modules lies 12m (40ft) deep in the water

Neutral buoyancy
The water provides 'neutral buoyancy', so astronauts who are training neither rise nor sink, simulating the effect of zero gravity

Hidden depths
The NBL is 61.6m (202ft) long by 31m (102ft) wide, but it still can't fit the entire ISS inside

Life support
Astronauts are connected to the pool's life support systems that provide air, power and communications, by 26m (85ft) long tethers

Safety
In 115,000 hours of dives, there has never been an accident with an astronaut. They are supported by a team of safety divers and cameramen

Breathing underwater
To avoid decompression sickness, astronauts in the pool breathe nitrox air that is 46 per cent pure oxygen

SURVIVE THE COSMOS

LIFE IN SPACE

Humans have had a presence in space in some form or another for half a century, but learning to live in the cosmos has been a steep learning curve. We take a look at what it's like to live in space, and how we've adapted over the years

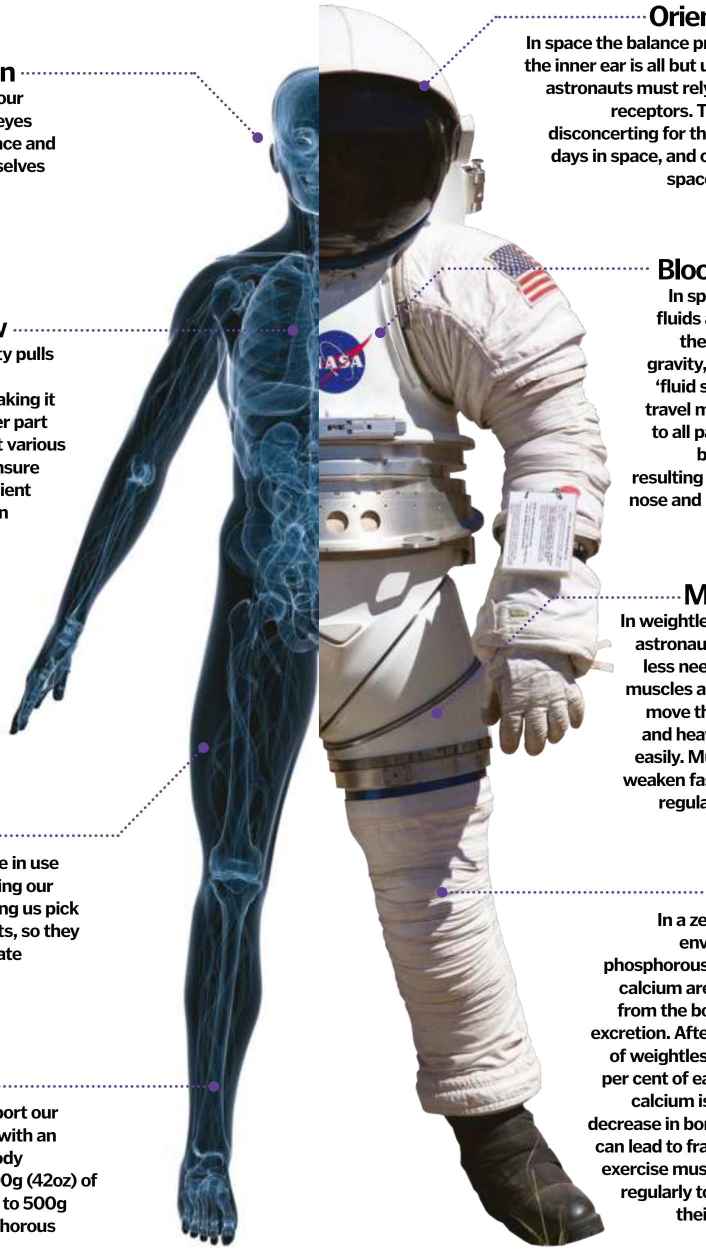
Living in space is the ultimate mental and physical test of the human body. On Earth, the experience of being in space is almost impossible to replicate; the closest astronauts can get is to train underwater but, even then, the experience is a world away from that first journey into orbit or beyond. There's no 'up' or 'down' in space, so many of their sensory receptors are rendered useless, while materials such as water behave completely differently to how they do on Earth. So, how do astronauts cope, and what's it like to actually live in space? We're about to find out.

Since Yuri Gagarin became the first man to leave the Earth in 1961, life in space has altered and improved dramatically. Gagarin spent the entirety of his 108-minute flight encased in a spacesuit, but nowadays astronauts can wear the same shorts and T-shirts they'd wear at home. The first space station, Russia's Salyut (launched in 1971), saw astronauts eat food from freeze-dried packets and stay only briefly on the station in order to survive. Now, astronauts aboard the International Space Station (ISS) can eat pizza and curry, reuse and recycle many of their utilities and can stay in orbit for hundreds of days.

Before the ISS there were many unknowns about living in space. Indeed, on the earlier space stations Mir and Skylab, procedures and equipment were much less advanced than they are now. For one thing, it was quickly realised that

Space bodies

How does living in space affect the human body?



EARTH
Orientation
On the ground our inner ears and eyes help us to balance and coordinate ourselves

SPACE
Orientation
In space the balance provided by the inner ear is all but useless, so astronauts must rely on visual receptors. This can be disconcerting for the first few days in space, and can lead to space sickness

EARTH
Blood flow
On Earth, gravity pulls our bodily fluid downwards, making it pool in the lower part of our body, but various mechanisms ensure there is a sufficient flow to the brain

SPACE
Blood flow
In space bodily fluids are free of the effects of gravity, known as 'fluid shift'. They travel more easily to all parts of the body, often resulting in a stuffy nose and puffy face

SPACE
Muscles
In weightlessness an astronaut will have less need for their muscles as they can move themselves and heavy objects easily. Muscles will weaken fast without regular exercise

EARTH
Muscles
Our muscles are in use every day, moving our limbs and helping us pick up heavy objects, so they do not deteriorate

SPACE
Bones
In a zero-gravity environment, phosphorous and bone calcium are removed from the body during excretion. After ten days of weightlessness, 3.2 per cent of each bone's calcium is lost. This decrease in bone density can lead to fractures, so exercise must be taken regularly to maintain their strength

EARTH
Bones
Our bones support our body on Earth, with an adult human body containing 1,200g (42oz) of calcium and up to 500g (18oz) of phosphorous

astronauts must sleep near a ventilation fan. If they don't they run the risk of suffocation. This is because, as they sleep, warm air does not rise in a weightless environment. In a badly ventilated area they would be surrounded by a bubble of their own exhaled carbon dioxide. A regular supply of air (oxygen) is needed to allow for regulated breathing.

Over the years sleeping methods have changed, from slumbering in a sleeping bag attached to a wall, on NASA's Space Shuttle, for example, to having their own small compartment on the ISS. Sleeping isn't easy, either. Astronauts experience a sunrise and sunset every 90 minutes as they fly at 24,945km/h (15,500mph) around the Earth, so clocks on the ISS are set to GMT and astronauts live their days just as they would on Earth. They work for over eight hours on weekdays, but on weekends they are given much more leisure time, although work must still be done to keep the ISS safe and operational, in addition to checking on experiments. Life in space isn't tough just for humans; animals have struggled as well. On NASA's Skylab space station in the Seventies, spiders were taken up

An authentic mockup of the Red Planet itself was also re-created

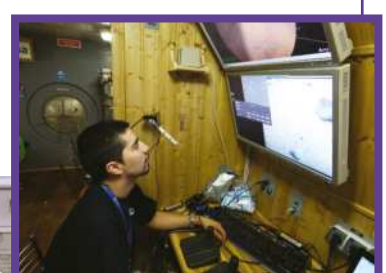
Mars 500

How to mentally overcome a deep-space mission

In 50 years of space exploration, the furthest a human has been from Earth is the far side of the Moon. While astronauts have spent hundreds of days aboard the ISS, the complexities of tackling a deep-space mission are relatively unknown. As a result, projects such as the Mars 500 mission have been given increasing precedence.

The Mars 500 mission was an important study to ascertain the mental and physical strain on humans in closed isolation on a long-haul trip. The mission was a joint project between the ESA and Russian Institute for Biomedical Problems, which ran from 3 June 2010 to 4 November 2011. Six candidates were sealed in an isolation chamber for 520 days, the approximate journey time for a real trip to and from the Red Planet. The chamber contained several modules designed to replicate a Martian spacecraft and the surface of Mars itself. The volunteers were subjected to some of the conditions they would experience, such as delayed communications and confined quarters. The results will be used to develop countermeasures to remedy potential problems.

The astronauts carried out the same day-to-day routine they would on a real-life mission to Mars



Space was very limited in the Mars 500 'shuttle'

to see how they would cope in a weightless environment. While disoriented they still managed to spin a web, even if it was a little wonky. More famous was the first living animal to be sent into space from Earth, Laika the dog from Russia. Sadly, she perished in orbit, but she was said to cope well with the experience of weightlessness. At the very least, Laika proved that animals could survive in space, providing the basis for Gagarin's later mission and all future human missions into the cosmos.

Each human consumes 0.9kg (2lbs) of oxygen daily, which is enough to fill a 3.5 cubic metre (123.6 cubic feet) room, and drinks 2.7kg (6lbs) of water. Therefore, the life-support systems on board the ISS recycle as much waste as possible, including that from urine and condensed moisture in the air, both of which are purified and reused, often after being broken down by electrolysis to provide fresh oxygen. However, not all water can be reused, and thus astronauts must rely on regular re-supply vehicles to bring cargo to the station. These have been performed by several spacecraft over the years, such as NASA's Space Shuttle until its retirement in July 2011, but they are now largely carried out by the ESA's Automated Transfer Vehicle (ATV). The ATV brings fresh food, clothes, water and equipment to the station. Once the cargo has been delivered, astronauts fill the vehicle with 5,896kg (12,998lbs) of waste and it is sent to burn up in Earth's atmosphere.

These are just some of the many ways that astronauts have adapted to life in space, and as more and more time is spent on the International Space Station, our capabilities to perform in a weightless environment will no doubt improve. The ultimate goal of sending humans to an asteroid and Mars in the 2030s is looking like an increasingly achievable objective thanks to the tireless work of space agencies worldwide over the last 50 years.


The ESA-built Cupola is a popular module where astronauts can get a fantastic view of Earth

A DAY IN SPACE

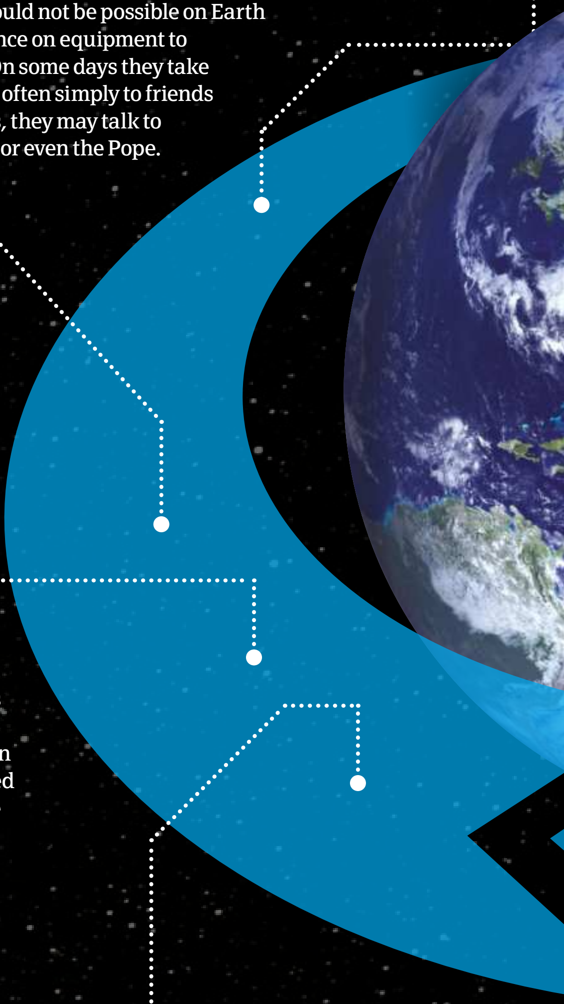
Astronauts aboard the ISS experience 15 'dawns' every day, but while they're on board the station they operate according to GMT so they can stay in direct contact with the ground at operational hours. Here's how a typical day pans out for an astronaut on the station

08:00 Daily conference/work

In the morning astronauts perform the first of their daily tasks assigned by ground control. They often have a daily conference where they discuss their jobs for the day. Their work consists of supervising experiments that would not be possible on Earth or performing routine maintenance on equipment to ensure the survival of the crew. On some days they take video calls from Earth. These are often simply to friends and family but, on rare occasions, they may talk to schoolchildren, the US president or even the Pope.

06:40 Breakfast/getting ready

Astronauts eat their first meal of the day, which is nothing like the freeze-dried food of the Apollo missions. Fresh fruit and produce are stored on the ISS, while tea and coffee are available in packets. Astronauts can wear anything from shorts and T-shirts to trousers and rugby shirts. However, there are no washing machines, so clothes must be allocated for specific days (although in such a clean environment they pick up very little dirt). Most clothes are disposed of every three days, but socks can be worn for up to a month, while a pair of underwear must be taken for each day on the station.



06:00 Post-sleep

Astronauts are woken up at 6am. On the ISS most astronauts have their own sleeping compartments, small spaces where the astronaut can lie vertically (although this doesn't matter as there is no 'up' or 'down' on the station). After waking they will get washed and dressed before eating breakfast, much like a regular day on Earth. There is a shower on the ISS, although most washing is done with a simple wet cloth. In the shower, water is squirted out from the top and 'sucked' by an air fan at the bottom, but water must be used sparingly. Grooming techniques such as shaving are difficult on the ISS, as surface tension makes water and shaving cream stick to an astronaut's face and the razor blade in globules.

10:00 + 17:00 Physical exercise

Astronauts must exercise regularly, at least 2.5 hours a day, to keep their body in optimum condition while in space. As explained previously, bones and organs can become frail and weak in a weightless environment. Therefore astronauts on the ISS have a variety of exercise machines, like treadmills and cycling machines, to keep them strong.

13:00 Lunch

Prolonged microgravity dulls tastebuds, and the white noise doesn't help (like being on an aircraft), so foods with strong flavours (such as spicy curries) are often the preferred choice for meals.

14:00 Back to work

On rare occasions astronauts will have to leave the station on an extra-vehicular activity (EVA). For this astronauts will don a spacesuit and perform work outside the ISS. Before they leave they must exercise for several hours in a decompression chamber to prevent suffering from the 'bends' on entering space. Work outside the station ranges from maintenance to installing or upgrading a component.

19:30 Pre-sleep

In the evening astronauts eat dinner in a communal area. This is an important time for social interaction, as often many hours are spent working alone on the station. Before sleep, they also have a chance for a bit of entertainment, which can range from watching a DVD to playing guitar.

21:30 Sleep

In space no one can hear you scream, right? Well, in an orbiting craft, space is actually very loud, with a multitude of fans and motors ensuring that the space station remains in the correct operational capacity. At 21.30pm astronauts head off to their designated sleeping compartments to grab some rest and, while reassuring, these noises can take a while to get used to for astronauts staying on the station for the first time, much like living next to a busy main road on Earth.

On board the International Space Station

What's it like to live in space?

Man has had a continuous presence in space since 2000 on the International Space Station. In 1998, the Zarya module was launched into orbit by the Russian Federal Space Agency. This was the first piece of the ISS. Now that it is complete, the ISS is the largest satellite to ever orbit the Earth. After being finished in 2012, the ISS is also arguably the most expensive single object to ever be constructed at more than $150 billion.

The ISS wasn't the first space station, however; in 1971 the Soviet Union launched the Salyut, which was the first in a series of space stations. Two years later, NASA launched Skylab. However, both of these programmes were single modules with limited life spans. In 1986, the Soviet Union launched the Mir, which was intended to be built upon and added to over time. The United States planned to launch its own space station, Freedom, just a few years later, but budgetary restraints ended the project. After the fall of the Soviet Union, the United States began negotiating with Russia, along with several other countries, to build a multinational space station.

Until Expedition 20 in May 2009, crews on the International Space Station consisted of two-to-three astronauts and cosmonauts, who stayed for six months. Now the ISS is large enough to support a six-man crew, the stay has been reduced to just three months. The current crew consists of: NASA commander Barry Wilmore and flight engineers Alexander Samokutyaev (RKA), Anton Shkatlerov (RKA), Terry Virts (NASA), Samantha Cristoforetti (ESA) and Elena Serova (RKA).

The crew typically works for ten hours a day during the week and five hours on Saturdays. During their eight scheduled night hours, the crew sleeps in cabins while attached to bunk beds, or in sleeping bags that are secured to the wall. They also have to wear sleep masks, as it would be difficult to sleep otherwise with a sunrise occurring every 90 minutes.

All food is processed so it is easy to reheat in a special oven, usually with the addition of water. This includes beverages, which the crew drinks with straws from plastic bags. Exercise is a very important part of daily life for the crew of the ISS because of microgravity's adverse effects on the body. The astronauts and cosmonauts may experience muscle atrophy, bone loss, a weakened immune system and a slowed cardiovascular system, among other problems. To help counteract this, the crew exercises while strapped to treadmills and exercise bicycles.

Research is the main reason for the station's existence in low Earth orbit (about 330 kilometres above the planet's surface). Several scientific experiments spanning fields including astronomy, physics, materials science, earth science and biology take place on the station simultaneously. Between September 2012 and March 2013, for example, expedition crews (33 & 34) worked on over 100 experiments in a wide range of fields, spanning biology and biotechnology, the earth and space sciences as well as

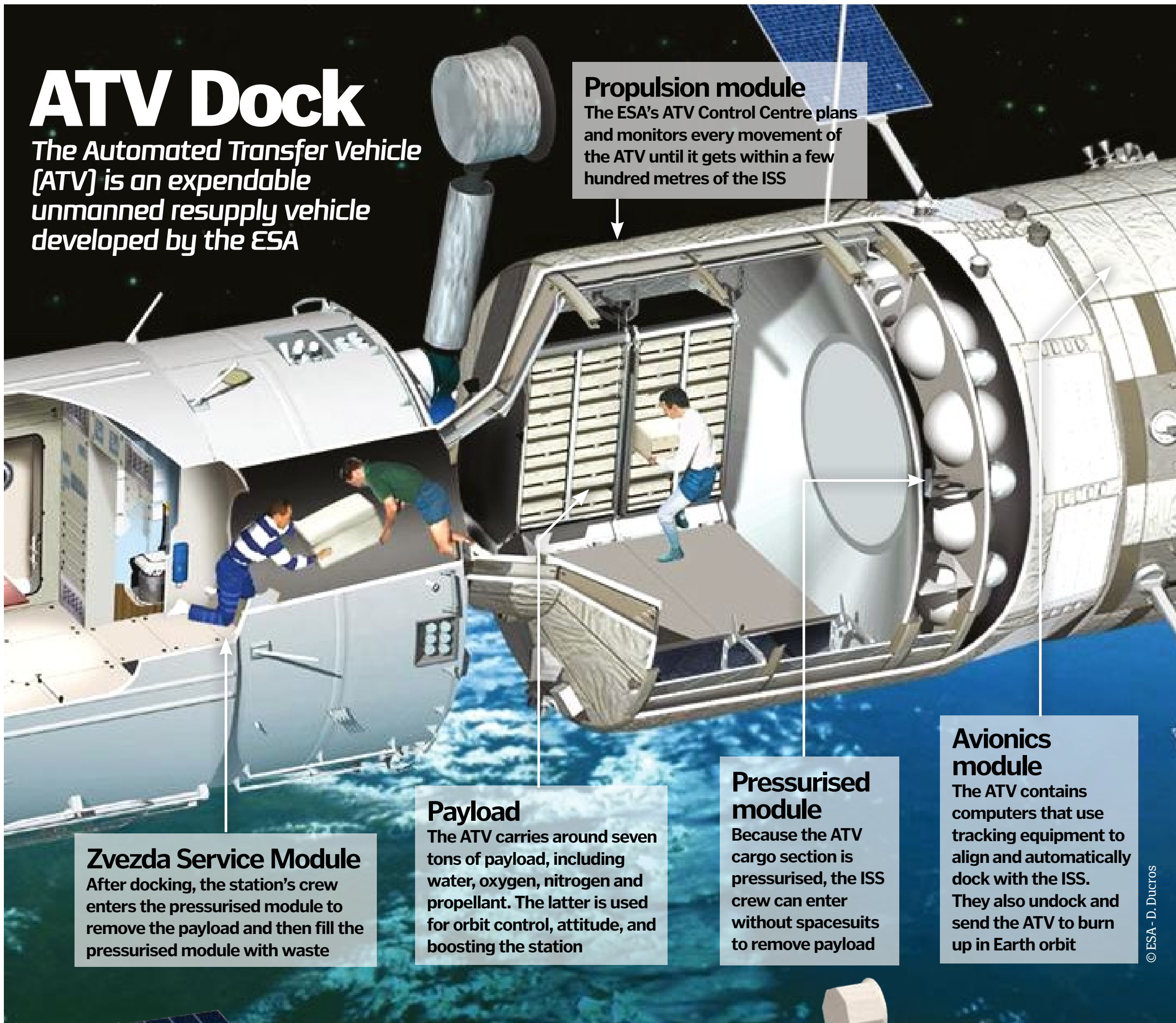
technological development. The conducting of experiments aboard the ISS is continuous, and each month brings more published research too.

One of the over-arching research goals for the station is to learn about the long-term effects of space on the human body. Many of the experiments also study the different ways things react in a low gravity, low temperature environment. There is an experiment involving the use of ultrasounds so that remote doctors can diagnose medical problems (there is no doctor on the ISS), with the hopes that the technology can also be used on Earth.

The ISS is now all but complete. The next components to be added are Russia's Nauka module, which has been repeatedly delayed, and the European Robotic Arm, both scheduled for 2017. It is expected that the ISS will continue operation until at least 2020.

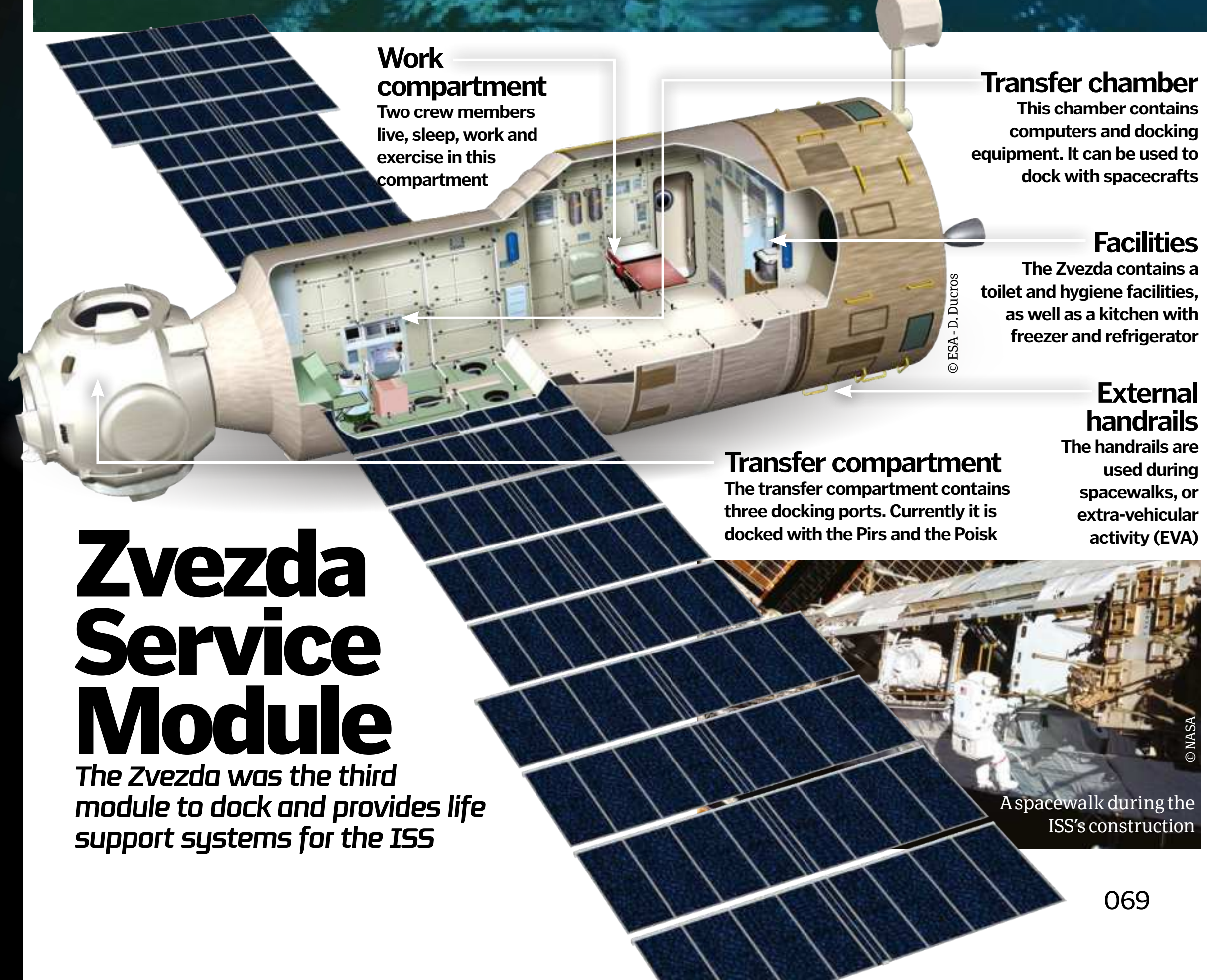
ATV Dock

The Automated Transfer Vehicle (ATV) is an expendable unmanned resupply vehicle developed by the ESA



Zvezda Service Module

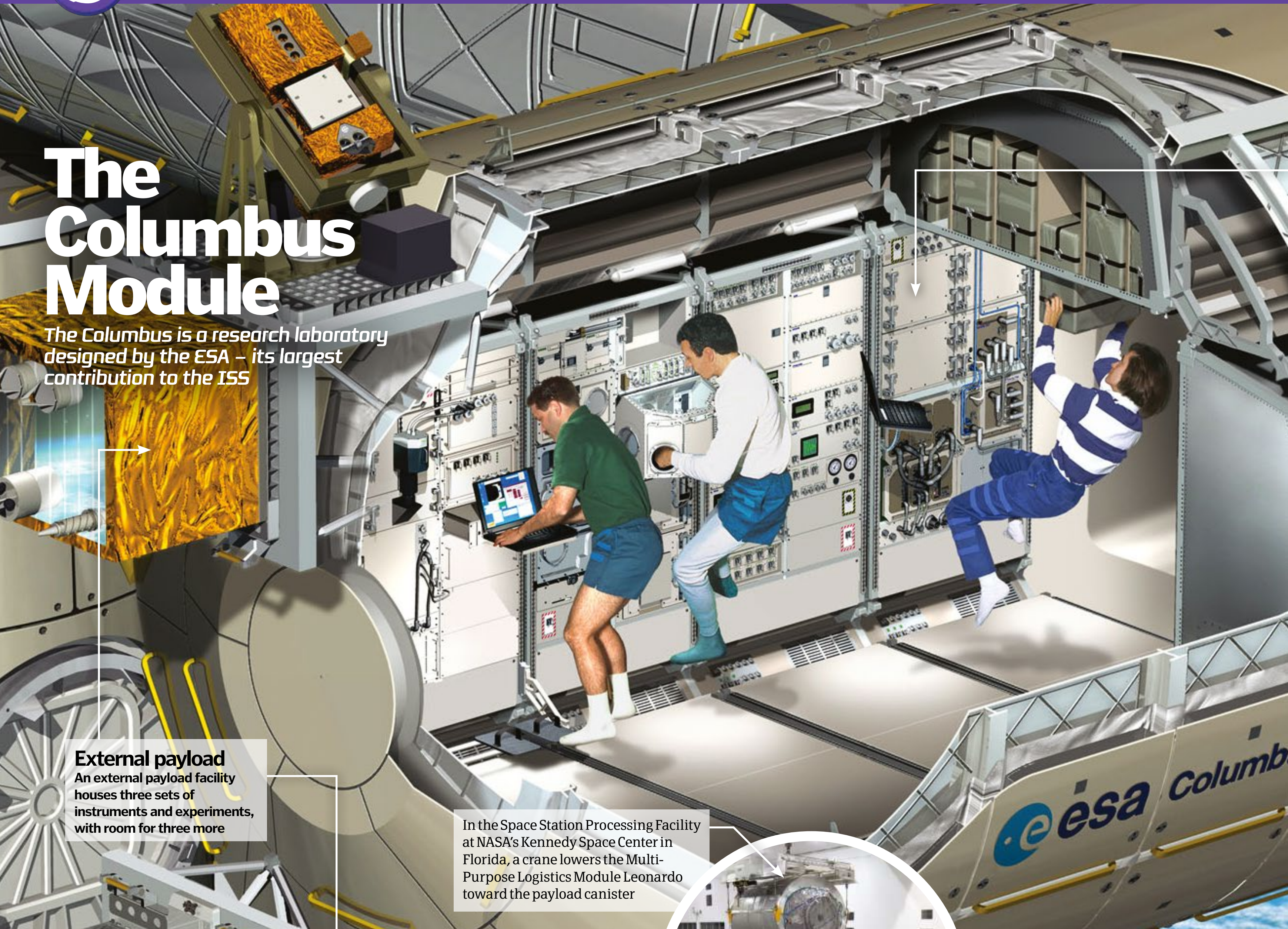
The Zvezda was the third module to dock and provides life support systems for the ISS



A spacewalk during the ISS's construction

The Columbus Module

The Columbus is a research laboratory designed by the ESA – its largest contribution to the ISS

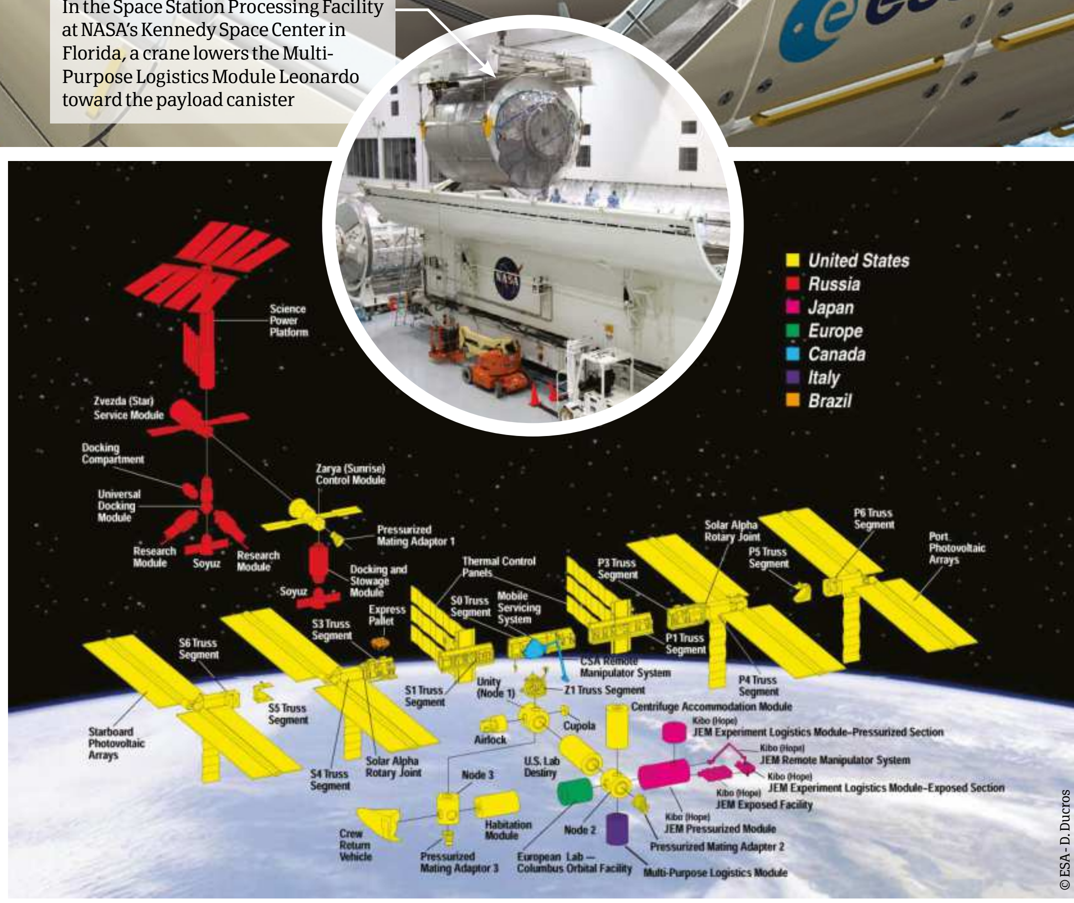


External payload
An external payload facility houses three sets of instruments and experiments, with room for three more

In the Space Station Processing Facility at NASA's Kennedy Space Center in Florida, a crane lowers the Multi-Purpose Logistics Module Leonardo toward the payload canister

Who built the ISS?

The ISS currently comprises 15 pressurised modules and an Integrated Truss Structure. The modules are contributions from the Russian Federal Space Agency (RKA), NASA, the Japanese Aerospace Exploration Agency (JAXA), the Canadian Space Agency (CSA) and the European Space Agency (ESA), which includes 18 member countries. A series of complex treaties and agreements govern the ownership, use and maintenance of the station. A further four modules are scheduled to be added.



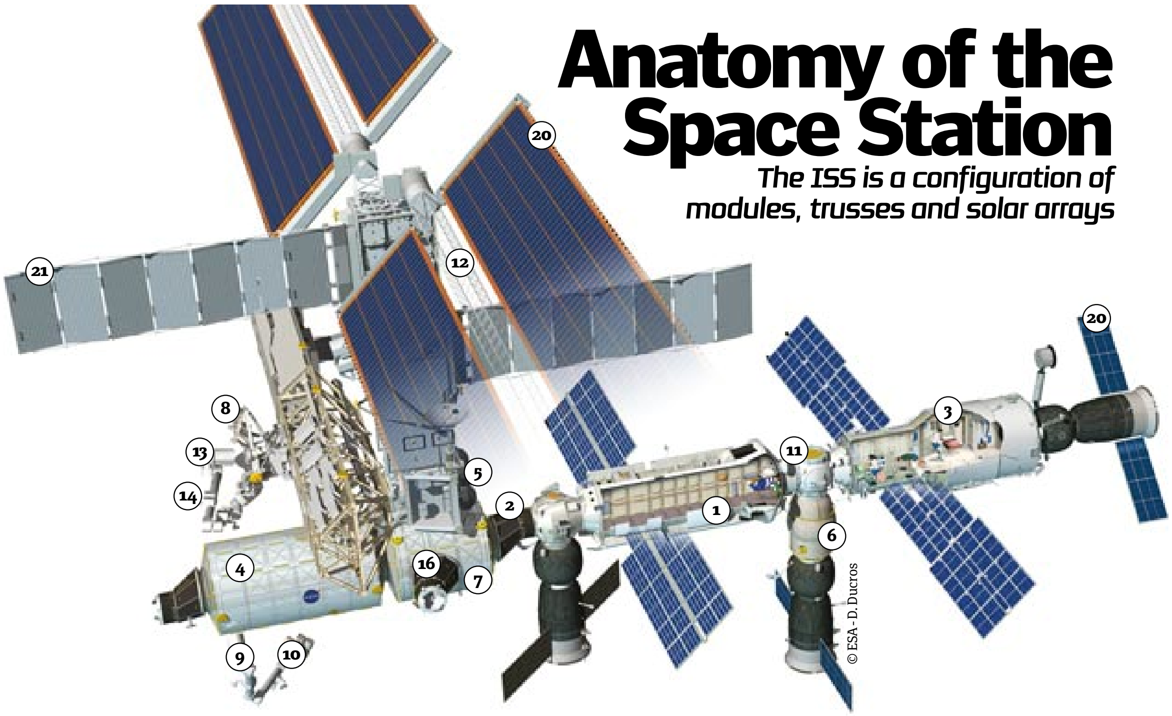
Creating water in space

For the crew of the ISS it's better not to think where their next glass of water is coming from

The ECLSS (Environmental Control and Life Support System) provides water with the Water Recovery System (WRS). Water from crew member waste, condensation and other waste water is distilled, filtered and processed. This water is then used for drinking, cooking, cleaning and other functions. An Oxygen Generation System (OGS) separates water into oxygen and hydrogen. An experimental Carbon Dioxide Reduction Assembly (CReA) uses the leftover hydrogen with carbon dioxide filtered from the crew cabins to produce usable water and methane. In addition, the ECLSS filters the cabin air, maintains cabin pressure and can detect and suppress fires.

Anatomy of the Space Station

The ISS is a configuration of modules, trusses and solar arrays



1. Zarya
The Zarya, launched in 1998 and built by the RKA, is now a storage component. As the first module it provided storage, power and propulsion.

2. Unity
Built by NASA and launched in 1998, Unity was the first node module to connect to the Zarya. It provides a docking station for other modules.

3. Zvezda
The RKA-built Zvezda launched in 2000. It made the ISS habitable by providing crew cabins and environmental control as well as other systems.

4. Destiny
The Destiny is a NASA laboratory. Launched back in 2001, it also contains environmental controls and works as a mounting point for the Integrated Truss Structure.

5. Quest
The 2001 NASA-built Quest is an airlock used to host spacewalks. The equipment lock is used for storing the spacesuits, while the crew lock allows exit to space.

6. Pirs
A mini-research module called Pirs was launched in 2001 by the RKA. It can dock spacecraft and also host spacewalks by cosmonauts.

7. Harmony
Harmony, built by NASA in 2007, is a node module. It serves as a berthing point and docking station for modules and spacecraft.

8. Columbus
The Columbus, launched in 2008, is an ESA laboratory specifically designed for experiments in biology and physics. It provides power to experiments mounted to its exterior.

9. Kibo Experiment Logistics Module
This JAXA module (also known as JEM-ELM) is part of the Japanese Experiment Module laboratory and was launched in 2008. It contains transportation and storage.

10. Kibo Pressurised Module
Also launched in 2008, the JEM-PM is a research facility and the largest module on the ISS. It has an external platform and robotic arm for experiments.

11. Poisk
The RKA-built Poisk (MRM2) launched in November 2009. In addition to housing components for experiments, it serves as a dock for spacecraft and a spacewalk airlock.

12. Integrated Truss Structure
The ISS's solar arrays and thermal radiators are mounted to this structure, which is more than 100 metres long and has ten separate parts.

13. Mobile Servicing System
Also known as the Canadarm2, this CSA-built robotic system used to move supplies, service equipment and assist astronauts on spacewalks.

14. Special Purpose Dexterous Manipulator
The SPDM, or Dextre, is a robot built by the CSA and is extremely dextrous. It can perform functions outside the ISS that had previously required spacewalks to happen.

15. Tranquillity
The Tranquillity is NASA's third node module, and was successfully launched in February 2010. It contains the ECLSS as well as berthing stations for other modules.

16. Cupola
The seven windows of this observatory module, launched with Tranquility in February 2010, make it the largest window ever used in space.

17. Rassvet
Launched in May 2010, this second RKA mini-research module also serves as storage.

18. Leonardo
A pressurised multipurpose module, the Leonardo was installed in March 2011. It serves as a storage unit and frees up space in the Columbus.

19. Nauka (MLM)
Scheduled to be launched with the European Robotic Arm in mid-2013, this multipurpose research module will be a rest area for the crew as well as doubling up as a research laboratory too.

20. Solar Arrays
These arrays convert sunlight into electricity. There are four pairs on the ISS.

21. Thermal Radiators
The Active Thermal Control System (ATCS) removes excess heat from the ISS and vents it out into space via these radiators.

The ISS in early construction while in orbit in 1999

The Statistics

The ISS

Mass: 419,455kg
Volume of habitable space: 388 cubic metres
Supplies: 2,722 kilograms per expedition
Orbit: 402 to 426km high at an angle of 51.6 degrees, travelling at 27,744kph, completing 15.7 orbits per day
Gravity: 88 per cent that of Earth sea level
Cost: US Government Accountability Office estimates a total of $100 billion (approx. £62 billion). ESA estimates a total of 100 billion euros (approx. £81 billion)
Crew support: 100,000+ ground personal, 500 contracting facilities in 37 states and 16 countries
Spacewalks: 28 shuttle-based and 127 ISS-based for more than 973 hours
Meals: About 22,000 consumed on board
Flights: 35 NASA space shuttle, 2 RKA Proton, 27 RKA Soyuz, 1 ESA Automated Transfer Vehicle, 1 JAXA H-II Transfer Vehicle
Mission control monitoring centres: 2 NASA centres, 1 RKA centre, 1 ESA in Germany, 1 ESA in France, 1 JAXA centre, 1 CSA centre

CURIOSITY'S GREATEST DISCOVERIES

The most sophisticated rover sent to another planet has found that Mars was once habitable

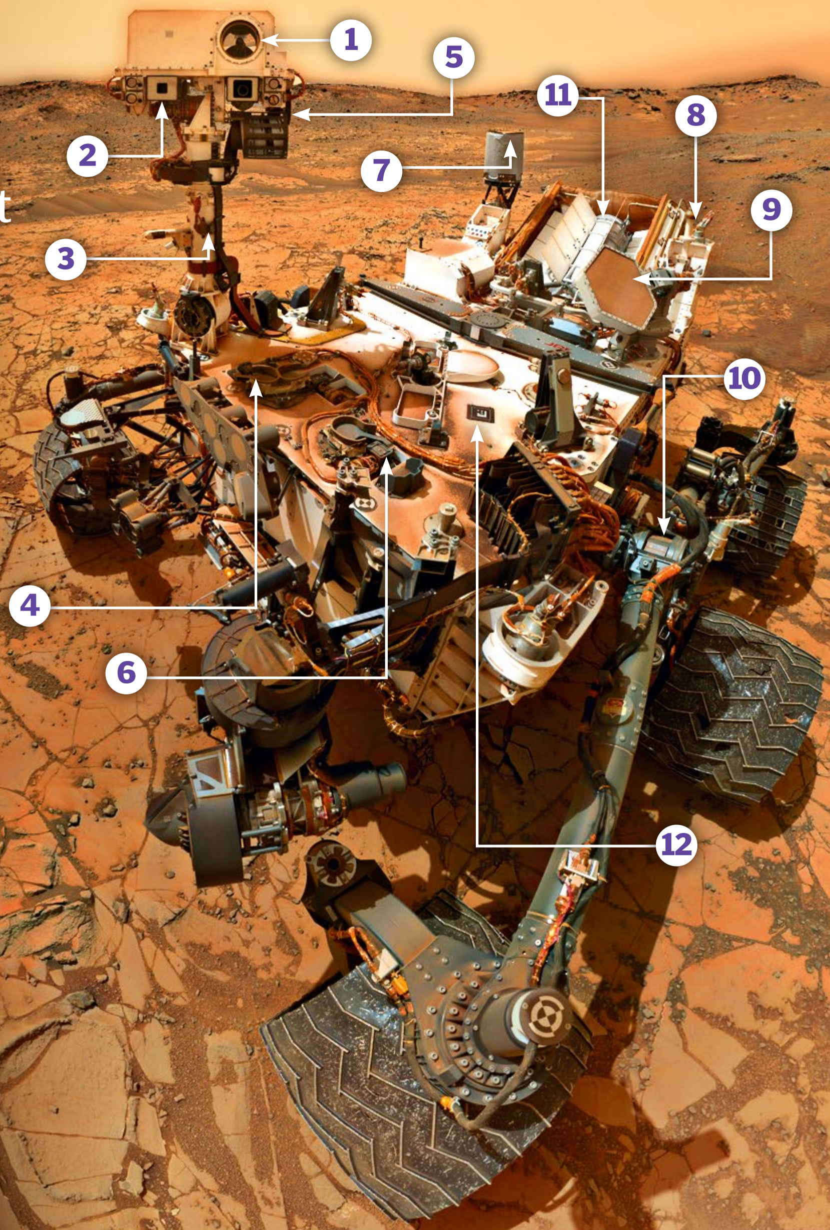
Today Mars is dry and barren. Barely any water flows on its surface and the air is thin and poisonous. But once upon a time, Mars was wet, possibly warm and could even have been home to microbial life.

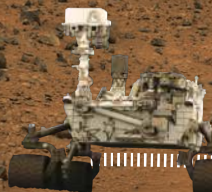
In 2004, NASA landed two robotic rovers called Spirit and Opportunity on Mars, and found conclusive evidence that water once ran on Mars' surface, perhaps as recently as a few million years ago. What scientists wanted to know next was whether this water contributed to an environment that could support life, so they sent another rover, the largest ever sent into space, to answer that question.

Curiosity is about the size of a family car. It is controlled by engineers back on Earth, whose commands can take up to 20 minutes to travel to Mars. Curiosity's computer brain uses software called AEGIS to identify objects of interest and to avoid hazards, such as steep slopes, large boulders or ditches, without scientists on Earth interfering.

Curiosity's rocker-bogie suspension system allows it to climb over obstacles while keeping all six of its wheels on the ground. The rover has 17 'eyes' – a system of cameras that can capture a three-dimensional map of the terrain within three metres (ten feet), which helps Curiosity judge the distance to obstacles in its way.

These technological innovations help support Curiosity's scientific goals. These include finding the chemical building blocks of life, investigating the mineralogy of the Martian surface and measuring radiation and other conditions in the atmosphere.

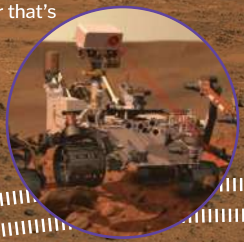




6 August 2012
Arrival on Mars
Curiosity's daredevil landing is dubbed 'seven minutes of terror', featuring atmospheric entry, parachutes, retro rockets and a 'sky crane' to lower the rover to the surface

10-13 August 2012
Brain transplant
New software, uploaded during the rover's flight to Mars, is installed to make Curiosity better at spotting hazards as it drives along

19 August 2012
Laser power
Curiosity uses the laser that's part of its Chemistry & Camera (ChemCam) instrument for the first time to analyse the composition of a basaltic rock called 'Coronation'



22 August 2012
On the road
Curiosity sets off, driving around and exploring its landing site, known as 'Bradbury Landing'

1 ChemCam
This laser zaps a target such as a rock, heats it and creates a burst of vapour. ChemCam then studies this vapour and identifies elements within it.

2 Navcams
A stereo pair of cameras provides a view of the landscape to aid navigation.

3 REMS
The Rover Environmental Monitoring Station (REMS) is a weather station, able to measure temperature, air pressure and wind speed.

4 SAM
The Sample Analysis at Mars (SAM) instrument suite looks for the chemical building blocks of life in rock and dirt samples.

5 Mastcam
The Mastcam takes colour video and images of the terrain, stitching them together to create panoramas.

6 CheMin
The Chemistry and Mineralogy instrument (CheMin) analyses various Martian minerals.

7 UHF antenna
The ultra-high frequency antenna sends all the data and images back to scientists on Earth.

8 DAN
The Dynamic Albedo of Neutrons (DAN) instrument looks for the presence of water.

9 High-gain antenna
Commands are uplinked to the rover via the high-gain antenna on a daily basis.

10 MARDI
The Mars Descent Imager (MARDI) took images of the surface to direct Curiosity to a safe landing.

11 RTG
The radioisotope thermoelectric generator (RTG) uses plutonium fuel to produce the electricity Curiosity needs.

12 RAD
The Radiation Assessment Detector (RAD) measures and identifies any high-level radiation.

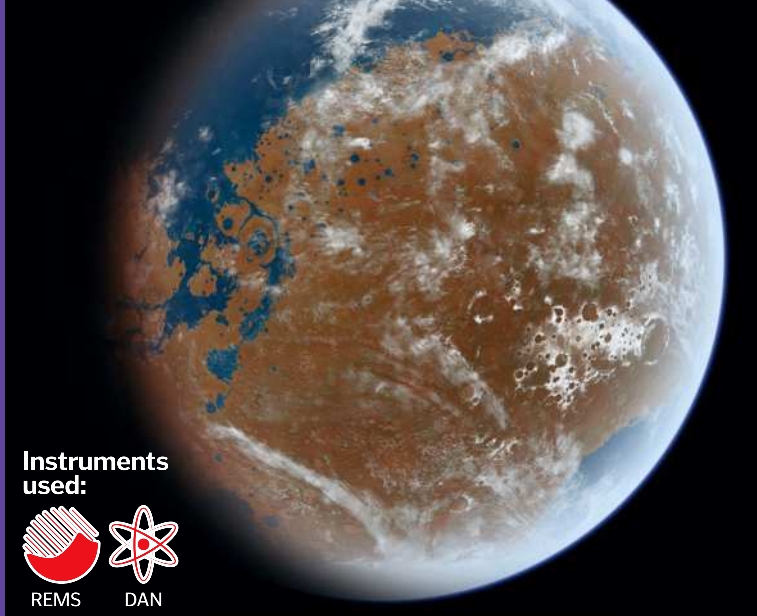
Mars could have supported life

Is there, or has there ever been, life on Mars? That's the big question. Scientists think that the Red Planet is lifeless now, but in the past it could have had a climate that would have supported microbial life. The evidence for this comes from 'tasting' the minerals and elements contained within the dirt and in old rocks that formed when Mars may have been habitable. Curiosity has found the likes of sulphur, nitrogen, hydrogen, oxygen, phosphorous and carbon in Martian rock. Some of these, like sulphur and hydrogen, are 'food' for microbes, oxygen is a possible by-product, while carbon, nitrogen and phosphorous are important building blocks for cells and DNA. Curiosity found these by sampling sedimentary rock in a region called Yellowknife Bay, where results indicate that liquid water was once present.


The view from within Yellowknife Bay

Instruments used:
SAM CheMin

Liquid water exists below the surface


Ancient Mars is thought to have had an abundance of water

Instruments used:
REMS DAN

The rovers Spirit and Opportunity were able to determine that rivers ran on Mars over 3.5 billion years ago and were the result of a thicker atmosphere, meaning Mars was once warmer and had a higher surface pressure. Curiosity has found that its landing site used to be a freshwater lake and that water played a major role in creating conditions suitable for microbial life.

Much of that water has since been lost to space, but there is still plenty on Mars. Most of it is locked up as ice in the polar caps, or as permafrost just below the dusty surface, stretching all the way from the poles to the mid-latitudes. However, recently Curiosity discovered evidence that water could still exist in a liquid state below the surface. Scientists speculate that the water would be kept liquid by being mixed with perchlorate salts, which could act like an anti-freeze down to around -70 degrees Celsius (-94 degrees Fahrenheit).

27 September 2012
Old streambed
Curiosity finds evidence for an ancient, gravelly streambed, where water flowed billions of years ago

30 October 2012
Minerals
Analysis of the Martian dirt finds it is filled with volcanic minerals, similar to the basaltic soils of Hawaii

9 February 2013
Drilling
Curiosity uses its drill for the first time to bore into some Martian bedrock and retrieve a sample

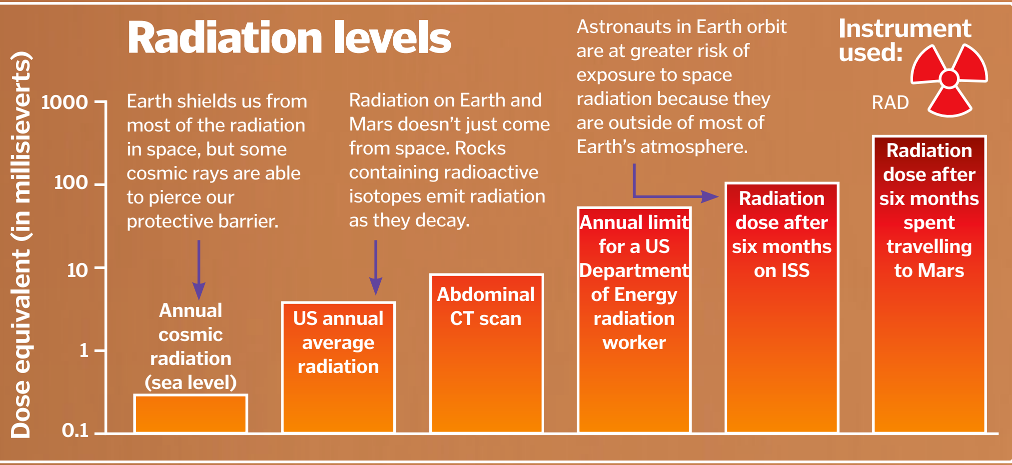
12 March 2013
Conditions for life
By studying the bedrock samples, scientists find elements such as oxygen, phosphorous and carbon, which could have supported microbial life on Mars in the distant past

6 June 2013
Long-distance driving
After exploring, Curiosity prepares to switch to distance-driving mode to begin the long trek towards its primary destination: Mount Sharp

Radiation could endanger humans

Mars is a dangerous world for humans, and one of the challenges that astronauts will face when they finally land on the Red Planet is coping with the radiation from space. Unlike Earth, Mars does not have a thick atmosphere or a magnetic field to deflect away radiation, which mostly comes from the Sun, or from cosmic rays. However, Curiosity's Radiation Assessment Detector (RAD) has found that the exposure on the surface is not as bad as in space. During the first 300 days of the mission, RAD measured the daily radiation dose to be 0.67 millisieverts per day. In space the daily dose is 1.8 millisieverts, meaning astronauts are most at risk when travelling between Earth and Mars.

Radiation levels



Instrument used: RAD

Mars was once warm and wet

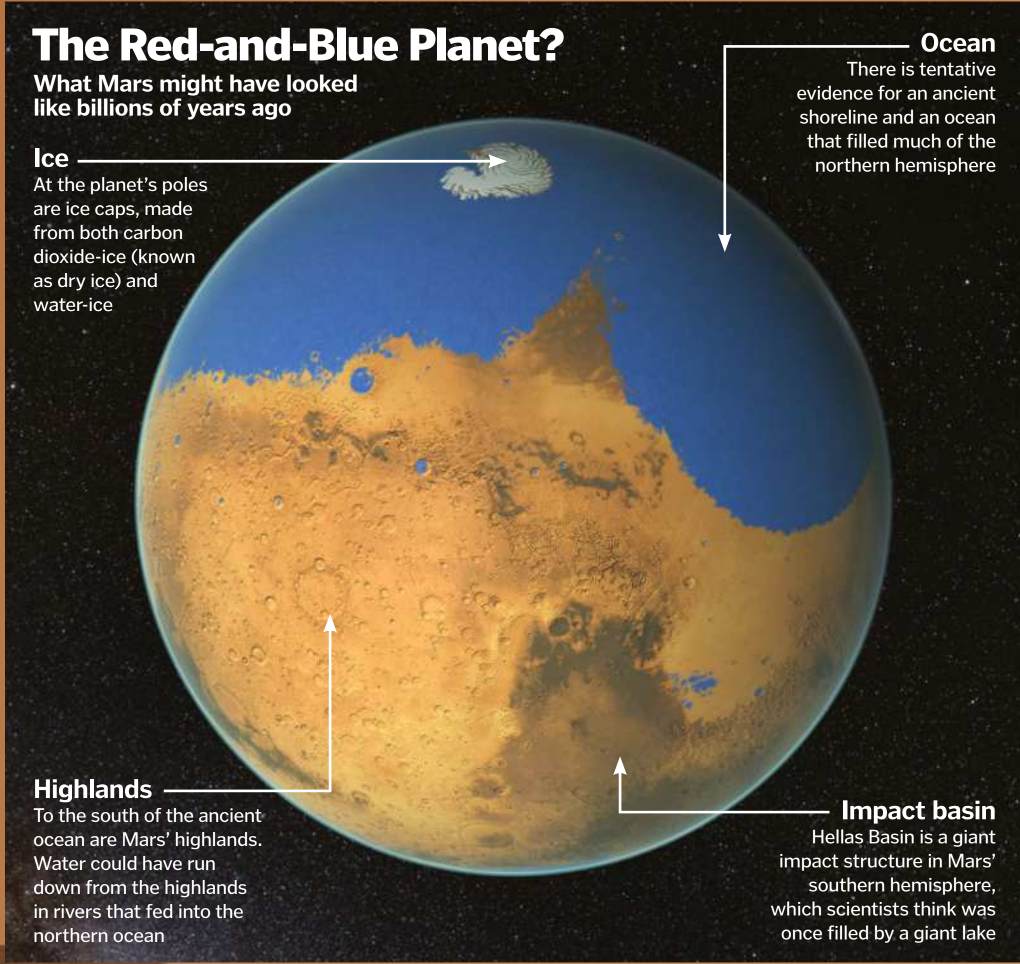
Instrument used: SAM

Mars once had a much thicker atmosphere than it does now, providing the surface pressure and warmth for liquid water to exist. However, over billions of years, Mars' atmosphere has been lost, as the planet's gravity has not been strong enough to hold onto it. In particular, solar wind has stripped away the upper layer of the atmosphere.

Curiosity has been able to determine the rate of loss of Mars' atmosphere by measuring xenon gas in the atmosphere. Xenon can exist as different isotopes – versions containing different numbers of neutrons – and the ratio of these isotopes changed as some were preferentially removed from the atmosphere.

Similarly, scientists have calculated that Mars has lost 87 per cent of its water by comparing the ratio of normal water, with oxygen and hydrogen atoms, to 'heavy' water, with oxygen and deuterium atoms. Normal water is lighter, so escapes more easily.

Gravel and rounded pebbles, embedded in sedimentary bedrock, are evidence for the action of water



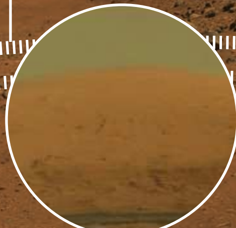
6 August 2013
A year on Mars
Curiosity celebrates a year on Mars, having returned almost 24 gigabytes of data to Earth, 36,700 images and driven a total of 1.6 kilometres (one mile)

5 December 2013
100,000 zaps
Curiosity fires its laser for the 100,000th time – an indication of how busy it's been since the rover landed!

9 December 2013
Radiation warning
After measuring the radiation on Mars for over a year with Curiosity, scientists reveal that astronauts on the surface will receive less than half the radiation exposure they will get in space

24 June 2014
A Martian year
Curiosity completes a full Martian year, which is 687 Earth days, on the surface of the Red Planet

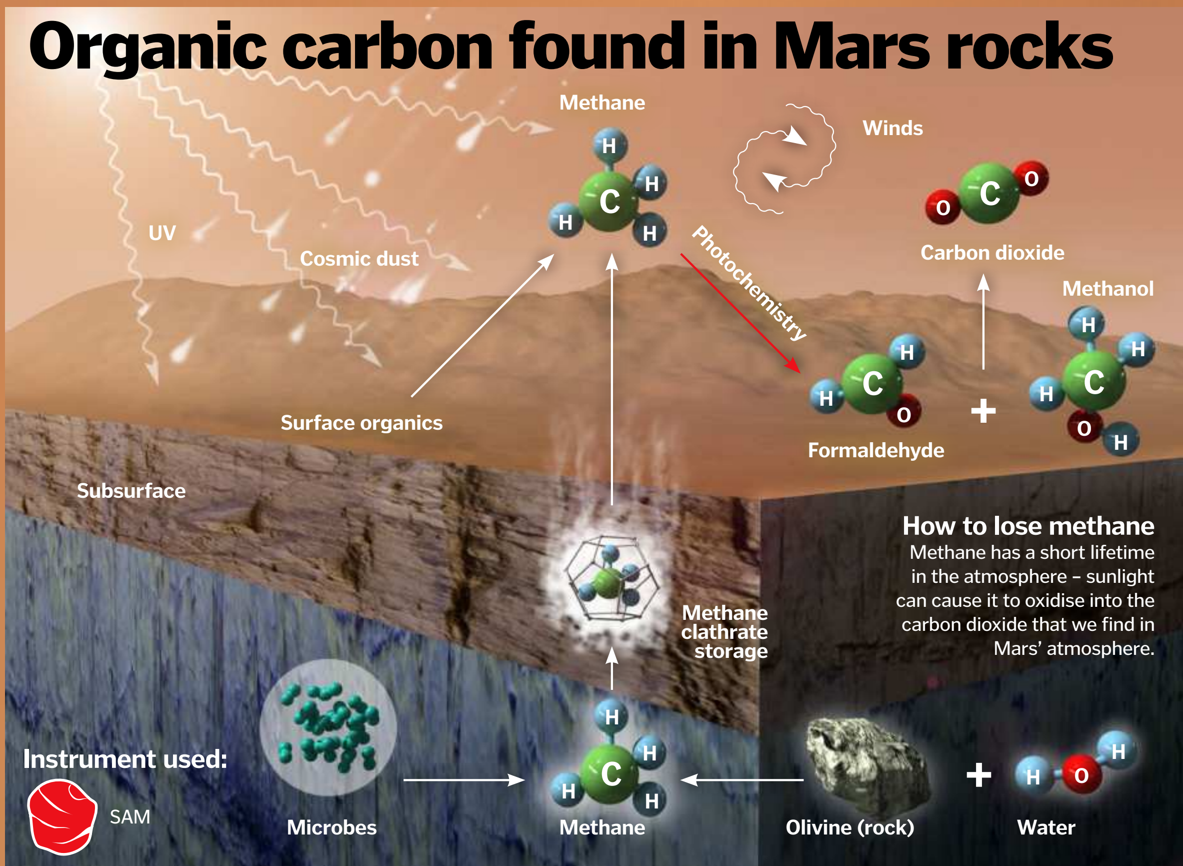
11 September 2014
Mount Sharp
After driving for 15 months, Curiosity finally arrives at the slopes of Mount Sharp



8 December 2014
How water shaped a mountain
Curiosity finds sedimentary layers in Mount Sharp, showing that the mountain was built gradually in a deep lake that filled Gale Crater

DID YOU KNOW? *Via Curiosity, will.i.am's Reach For The Stars was the first song to be beamed to Earth from another planet*

Organic carbon found in Mars rocks



Organic molecules and compounds, which are materials that contain carbon and are very useful for life, have been found in Martian rocks. The rover used its drill to dig into a rock that has been nicknamed 'Cumberland' and then sampled some of the powder produced by the drilling. Unfortunately however, Curiosity has been unable to identify the exact nature of the organic molecules in the powder because their chemical structure was altered when they were heated by the SAM instrument.

However, one example of an organic molecule, methane, has been detected by Curiosity. On two occasions, once during late 2013 and again early in 2014, the rover detected a spike in methane levels in the atmosphere. Methane is short-lived in the atmosphere, so had to be being produced relatively nearby. Living things can produce methane, but it can also result from geological processes too. At the moment the jury is still out on the origin of the methane; a geological origin is the most likely, but scientists cannot yet rule out the possibility that the methane is being produced by microbes. If it is, then that would be an astounding discovery.

Methane
A methane molecule is formed from one carbon atom and four hydrogen atoms.

Wind action
It is thought that methane is distributed across the Red Planet by Martian winds.

Underground
Methane may be trapped in icy lattices called clathrates. When the clathrates melt due to seasonal temperature changes, the methane leaks out through cracks and vents.

Geology
Geological action can also create methane. Liquid water under the surface can react with the mineral olivine, found in rocks, to create methane.

Ultraviolet
UV light from the Sun could produce methane by inducing reactions with either organic material on the surface or in cosmic dust falling through the atmosphere.

Biological process
Martian methane could potentially be created by biological processes, a result of being generated by tiny microbial life-forms.

What's next for Curiosity?

When Curiosity landed in the giant 154-kilometre (96-mile) wide Gale Crater, its central mountain, Mount Sharp, which is 5.5 kilometres (3.4 miles) tall, was always going to be an attractive destination. In September 2014, Curiosity arrived at the foothills of Mount Sharp, just over two Earth years after landing on Mars. Now its mission is to travel around the lower parts of the mountain, occasionally sampling sedimentary rock to determine more about the geological and chemical history of the area. The way the mountain is made of sediments that were laid down means that the oldest layers, dating back perhaps over four billion years, are found at the bottom. The aim will be to try and determine at what point the environment around the mountain turned from a freshwater lake into more acidic conditions, before drying up completely.

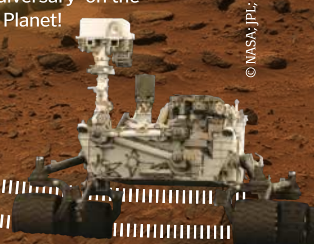
Rocky buttes and sedimentary layers on the foothills of Mount Sharp

16 December 2014
Methane
Curiosity detects a ten-fold spike in methane in the atmosphere surrounding it – but is it geological, or could it have a biological origin?

24 March 2015
Nitrogen
After heating a sample of sedimentary material from Mount Sharp, Curiosity detects biologically useful nitrogen in the form of nitric oxide

24 June 2014
Martian year
The Curiosity rover completed a Martian year or 687 Earth days after finding out that Mars once had environmental conditions favourable for microbial life

5 August 2017
Five years on Mars
The Curiosity rover celebrates its fifth 'landiversary' on the Red Planet!



Understanding ROCKET SCIENCE

Modern rocket science was used in entertainment and weaponry, long before the realms of space travel

Rocket science has been around since the 280s BCE, when ancient Chinese alchemists invented gunpowder. Initially used in fireworks, gunpowder was soon put to use in weaponry as fire-arrows, bombs and more. Through the centuries, rockets continued to be used as weapons until the early 20th century. In 1912, Robert Goddard built the first liquid-fuel rocket (previous rockets were solid-fuel) and began the age of modern rocketry. To date, there have been about 500 rocket launches from NASA's Cape Canaveral, and more than five thousand satellites launched by rockets from spaceports around the world.

While the term 'rocket' can be used to describe everything from cars to jet packs, most of us think 'space travel' when we imagine a rocket. Most rockets follow the same basic design. Typically they are tube-like in shape, with stacks of components. Rockets carry propellants (a fuel and an oxidiser), one or more engines, stabilisation devices, and a nozzle to accelerate and expand gases. However, there's a lot of variation among those basic elements.

There are two main types of rockets: solid-fuel and liquid-fuel. The former have some similarities to those early gunpowder rockets. For space applications, solid-fuel rockets are often used as boosters to lower the amount of needed liquid fuel and reduce the overall mass of the vehicle as a whole. A common type of solid propellant, used in the solid rocket boosters on the NASA space shuttles, is a composite made of ammonium percholate, aluminium, iron oxide and a polymer to bind it. The propellant is packed into a casing. Solid-fuel

rockets are used alone sometimes to launch lighter objects into low-Earth orbit, but they cannot provide the type of overall thrust needed to propel a very heavy object into Earth orbit or into space. They can also be difficult to control and to stop once ignited.

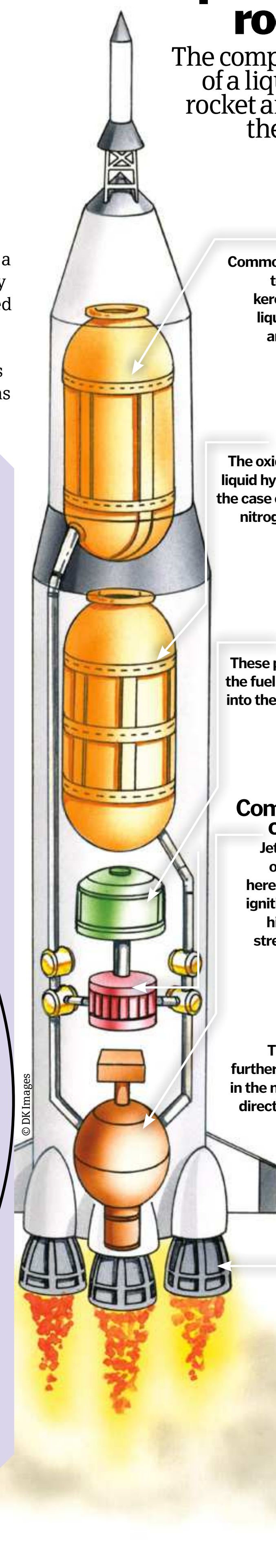
The difficulty in getting off the ground is due to the strength of Earth's gravity. This is why thrust – a rocket's strength – is measured in pounds or Newtons. One pound of thrust is the amount of force that it takes to keep a one-pound object at rest against Earth's gravity. A rocket carries fuel that weighs much more than the object that it's trying to move (its payload – a spacecraft or satellite). To understand why, think about what happens when you blow up a balloon and then release it. The balloon flies around the room because of the force exerted by the air molecules escaping from it. This is Newton's third law in action (see boxout on the following page). But the balloon is only propelling itself; rockets need to generate thrust greater than their mass, which includes the weight of the fuel. For example, the space shuttle in total weighs about 4.4 million pounds, with a possible payload of about 230,000 pounds. To lift this, rocket boosters provided 3.3 million pounds of thrust each, while three engines on the main tank each provided 375,000 pounds of thrust.

Liquid-fuel rockets have the benefit of losing mass over time as their propellant is used up, which in turn increases the rate of acceleration. They have a higher energy content than solid-fuel rockets. Typically they consist of a fuel and an oxidiser in separate tanks, mixed in a combustion chamber. Guidance systems control the amount of propellants that enter, depending on the amount of thrust needed. Liquid-fuel rockets can be stopped and started.

Launch location can also help rockets become more efficient. European Space Agency member country France chose to build a spaceport in French Guiana not only for its location near water, but also its location near the equator. Launching a rocket near the equator, in an easterly direction, makes use of energy created by the Earth's rotation speed of 465m per second. This also means that putting a rocket into geosynchronous orbit is easier, because few corrections have to be made to its trajectory.

Liquid-fuel rocket

The components of a liquid fuel rocket and how they work



Escape velocity

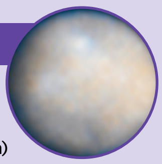
How rockets break free of Earth's gravity

Throw an apple into the air and it will keep travelling away from planet Earth until gravity overcomes the force of your throw. At this point the apple will fall back down to the ground. If, however, you launched that apple from a cannon at a speed of 25,000mph (40,000kph) – that's a nippy seven miles (11km) per second – the apple will reach what's known as escape velocity. At this speed, the force of gravity will never be stronger than the force causing the apple to move away from Earth, and so the apple will escape Earth's gravity.

Escaping other bodies

Escape velocity depends on the mass of the planet or moon, meaning that each planet's escape velocity is different

Ceres



Mass (Earth = 1): 0.00015
Escape velocity: 1,430mph (2,301kph)

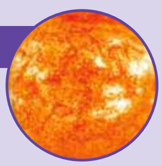
The Moon

Mass (Earth = 1): 0.012
Escape velocity: 5,320mph (8,561kph)

Earth

Mass (Earth = 1): 1
Escape velocity: 25,038mph (40,000kph)

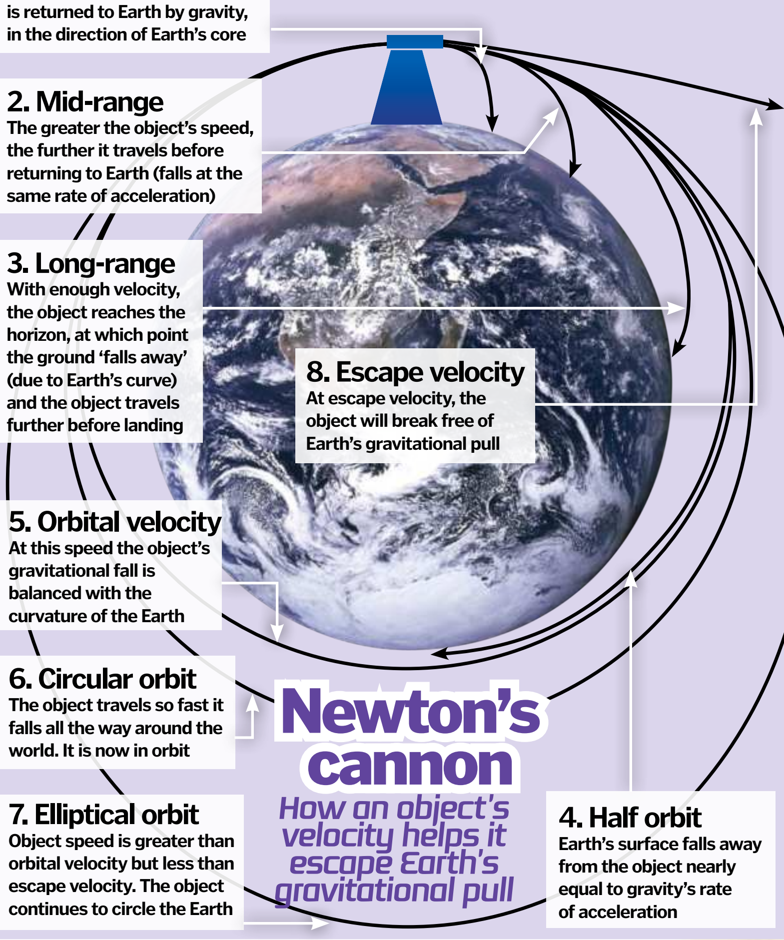
The Sun



Mass (Earth = 1): 333,000
Escape velocity: 1,381,600mph (2,223,469kph)

Newton's cannon

How an object's velocity helps it escape Earth's gravitational pull



The three laws of motion

Rockets have been around for thousands of years, but the science behind them wasn't understood until Isaac Newton's 1687 book *Philosophiae Naturalis Principia Mathematica*. In it, Newton explained three laws that govern motion of all objects, now known as Newton's Laws of Motion. Knowing these laws have made modern rocketry possible.

FIRST LAW

The first law states that objects that are at rest will stay at rest, while objects that are in motion will stay in motion unless an external, unbalanced force acts upon it. A rocket is at rest until thrust unbalances it; it will then stay in motion until it encounters another unbalanced force.

SECOND LAW

Force equals mass times acceleration. Force is the pressure from the explosions. It accelerates the rocket's mass in one direction and the mass of the expelled gases in the other. Mass decreases as it burns up propellants, while acceleration increases.

THIRD LAW

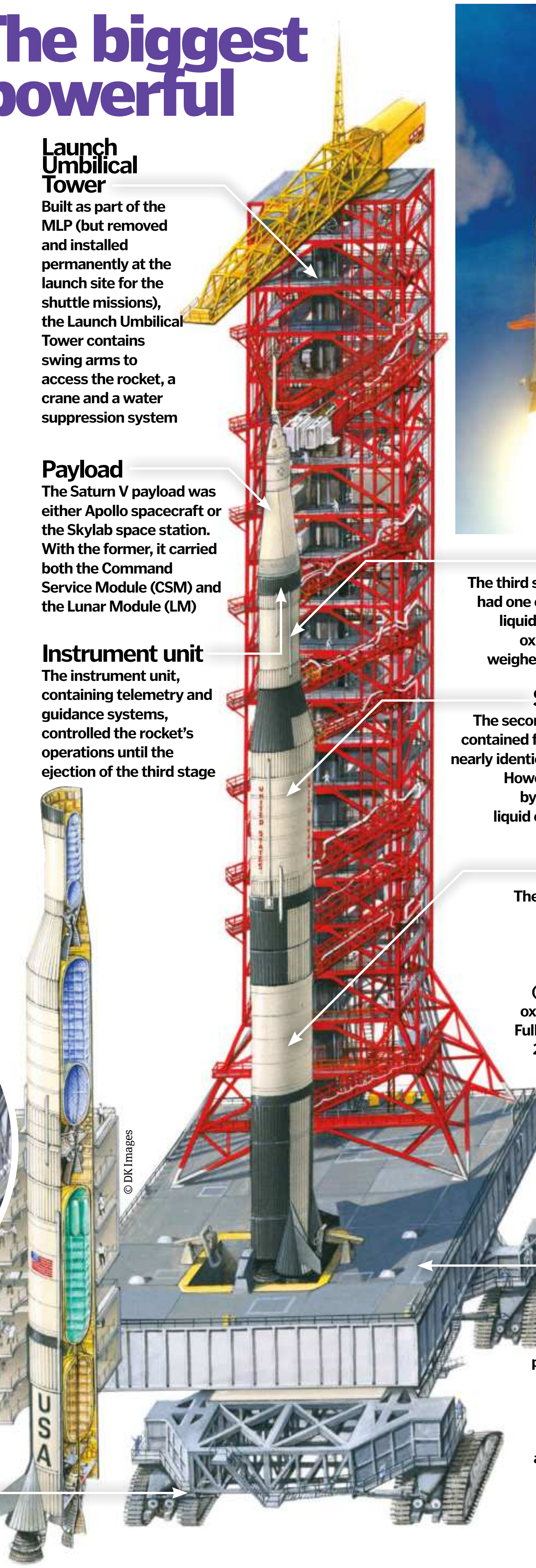
The third law states that for every action, there is an equal and opposite reaction. When a rocket launches, the action is the gas expelling from its engine. The rocket moves in the opposite direction, which is the reaction. To lift off, the thrust must be greater than the rocket's mass.

Saturn V: The biggest and most powerful

Rockets like Saturn V, the one used to launch NASA's Apollo and Skylab programs, are multi-stage liquid-fuelled boosters. The Saturn V is considered to be the biggest, most powerful and most successful rocket ever built. It was 110.6m tall, 10.1m in diameter and had a payload of 119,000kgs to low-Earth orbit.

There were three stages, followed by an instrument unit and the payload (spacecraft). The total mission time for this rocket was about 20 mins. The centre engine was ignited first, then engines on either side ignited. The first stage lifted the rocket to about 70km and burned for 2.5 mins. When sensors in the tanks sensed that the propellant was low, motors detached the first stage. The second stage continued the trajectory to 176km and burned for six mins. About halfway through this stage's ignition, the instrument unit took control of calculating the trajectory.

Second stage complete, solid-fuel rockets fired it away from the third stage. The third stage burned for 2.5 mins and stayed attached to the spacecraft while it orbited the Earth, at an altitude of 191.2km. It continued to thrust and vent hydrogen before ramping up and burning for six more minutes, so the spacecraft could reach a high enough velocity to escape Earth's gravity.



Launch Umbilical Tower

Built as part of the MLP (but removed and installed permanently at the launch site for the shuttle missions), the Launch Umbilical Tower contains swing arms to access the rocket, a crane and a water suppression system

Payload

The Saturn V payload was either Apollo spacecraft or the Skylab space station. With the former, it carried both the Command Service Module (CSM) and the Lunar Module (LM)

Instrument unit

The instrument unit, containing telemetry and guidance systems, controlled the rocket's operations until the ejection of the third stage

Third stage

The third stage is S-IVB. It only had one engine but also used liquid hydrogen and liquid oxygen. Fully fuelled, it weighed 119,000 kilograms

Second stage

The second stage, or S-II, also contained five engines and was nearly identical to the first stage. However, it was powered by liquid hydrogen and liquid oxygen and weighed 480,000 kilograms

First stage

The first stage was also known as S-IC. It contained a central engine, four outer engines, RP-1 fuel (kerosene) and liquid oxygen as the oxidiser. Fully fuelled, it weighed 2.3 million kilograms

Crawler Transporter

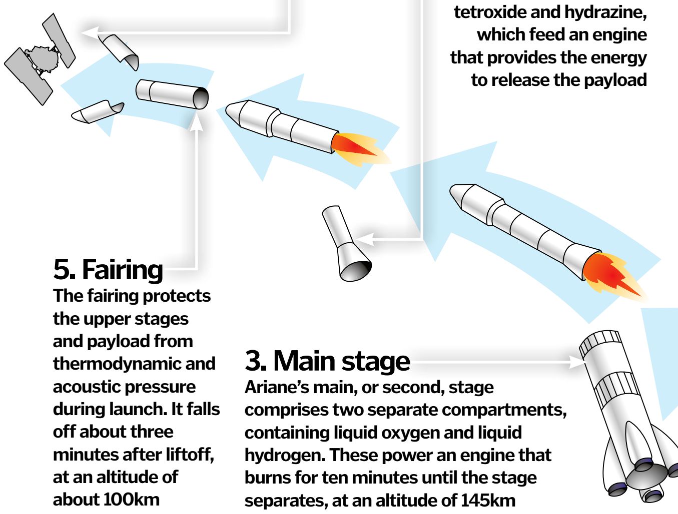
This tracked vehicle moved spacecraft from the Assembly Building to the launch complex along a path called the Crawlerway, and then moved the empty MLP back to the VAB

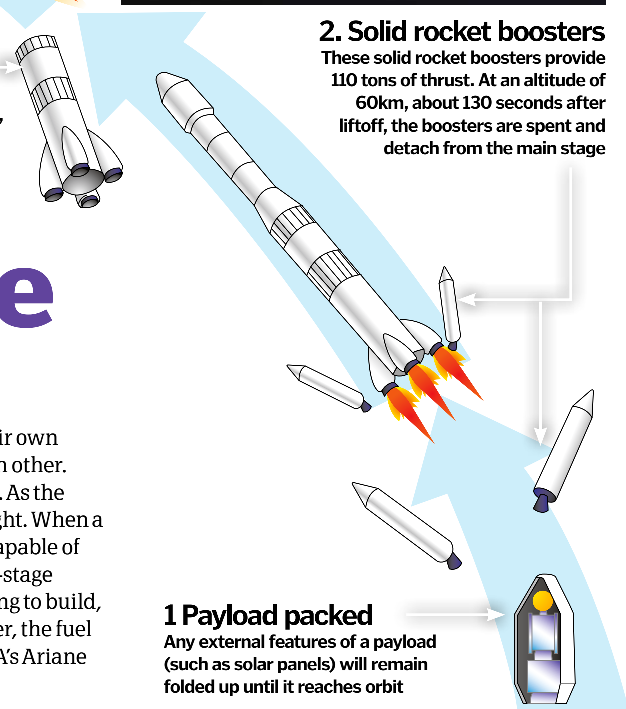
Mobile Launcher Platform (MLP)

A three-story platform designed to support and launch the Saturn V (and later, the space shuttle). Spacecraft are built vertically, in a ready-for-launch configuration, in the Vehicle Assembly Building (VAB)

Multi-stage rockets

Multi-stage rockets are multiple rockets (each with their own engines and fuel systems) stacked on top or beside each other. Sometimes this assembly is known as a launch vehicle. As the fuel burns, the container holding it becomes dead weight. When a stage separates from the main body, the next stage is capable of generating more acceleration. The downside of a multi-stage rocket is that they're more complex and time-consuming to build, and there are multiple potential failure points. However, the fuel savings are worth the risk. This example shows the ESA's Ariane rocket launching a satellite in Earth orbit.





1 Payload packed
Any external features of a payload (such as solar panels) will remain folded up until it reaches orbit

2. Solid rocket boosters
These solid rocket boosters provide 110 tons of thrust. At an altitude of 60km, about 130 seconds after liftoff, the boosters are spent and detach from the main stage

3. Main stage
Ariane's main, or second, stage comprises two separate compartments, containing liquid oxygen and liquid hydrogen. These power an engine that burns for ten minutes until the stage separates, at an altitude of 145km

4. Third stage
This third stage is known as the storable propellant stage. It contains two propellant tanks of nitrogen tetroxide and hydrazine, which feed an engine that provides the energy to release the payload

5. Fairing
The fairing protects the upper stages and payload from thermodynamic and acoustic pressure during launch. It falls off about three minutes after liftoff, at an altitude of about 100km

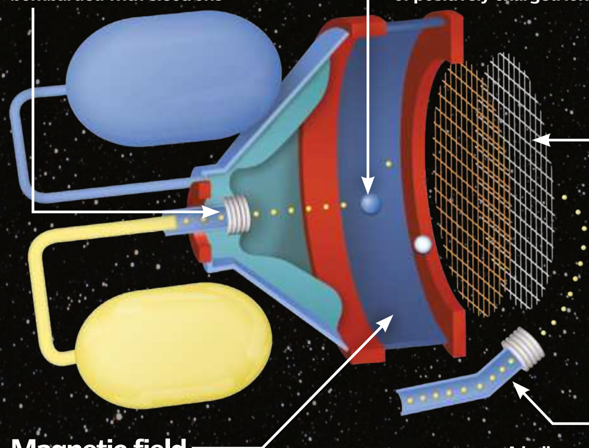
6. Payload launched
Ariane's payload, a satellite, is released by steel springs. The rocket is also capable of carrying and launching dual satellites and also delivered a spacecraft to the International Space Station

Here the Apollo 6 flight is shown between its first and second stage

© NASA

Ion engine propulsion

Both solid-fuel and liquid-fuel rocket engines generate thrust through chemical reactions, but in the future, rockets may be powered by ion engines while in space. An ion engine uses either electromagnetic or electrostatic force to accelerate ions, atoms with a net positive or negative charge. While the amount of thrust generated is comparatively low, the engine is more efficient and can last for a very long time.



Propellant injection
Ion engines use a propellant fuel, which is injected into a discharge chamber and bombarded with electrons

Collision
The collision of propellant atoms and electrons results in the release of positively charged ions

Multi-aperture grids
This series of grids extracts the positively charged ions and electrically accelerates them into ion jets, generating thrust

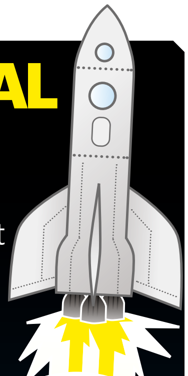
Cathode
A hollow cathode injects negatively charged electrons into the positively charged ion beam to render it neutral

Magnetic field
Magnetic rings generate a magnetic field that facilitates the ionisation process

© NASA

THE FINAL COUNT DOWN

Liquid-propellant rockets have come a long way since their inception…



1981
STS
NASA's Space Transportation System, which took the shuttle into orbit, was retired in July 2011 after a mighty 135 missions.

1967
Saturn V
The most powerful space rocket to date, Saturn V was taller than a 36-story building and launched every Apollo Moon mission.

1957
Sputnik
The Soviet Union's Sputnik Rocket launched the world's first satellite, Sputnik 1, a major landmark at the start of the 'Space Race' with the USA.

1944
V-2 Rocket
Developed by Germany for use at the end of WWII, the V-2 was the first rocket to achieve sub-orbital spaceflight.

1926
The first modern rocket
American Robert Goddard built the first successful liquid-propellant rocket. It climbed 12.5 metres before landing in a nearby cabbage patch.

The new breed of propulsion system that will take us to Mars and beyond

MEGA ROCKETS

The Delta II rocket launchedwith the Dawn spacecraft in 2007 to explore asteroids Vesta and Ceres

© NASA

The hardest part of exploring the final frontier is actually getting there in the first place. While mankind has been undertaking space-faring missions for over 50 years now, our methods of propulsion to escape Earth's influence have barely changed at all, and the fundamental problem of overcoming our planet's gravity is still readily apparent. When, years ago, people dreamed of regular space planes flying every week or space elevators lifting cargo into orbit, limitations and complexities have seen our forays beyond Low Earth Orbit (LEO) rely solely on vertically launching rockets. Unfortunately, these themselves bring with them a number of limitations – notably the amount of thrust that is needed to transport cargo into orbit and the cost considering that most rockets are almost entirely non-reusable. And so, as is the way with most things, the solution to take more cargo into orbit was relatively simple: make the rockets bigger. Much bigger.

Giant rockets are used predominantly to take loads such as satellites into orbit. Different rockets can travel to differing heights, with larger payloads unable to be transported into further orbits, while smaller payloads can be taken out to geosynchronous orbits over 32,000 kilometres (20,000 miles) above the surface of the Earth, and even beyond.

One of the major problems with rocket-powered flight is the sheer cost involved in taking even just a single kilogram into orbit. Most rockets that fly today are all but wholly non-reusable. This means the boosters that are jettisoned as the rocket makes its way to

The ESA's Ariane 5 heavy-lift rocket

© ESA

the cosmos are left to burn up in the atmosphere or, occasionally, are recovered from the sea where they have splashed down, but they are rarely designed to be flown again and again.

One company planning to tackle this problem is SpaceX, a US-based manufacturer that has been developing its own rockets for several years. The first of these, the Falcon 9, has already flown several times, but the next development will be the Falcon Heavy, a giant rocket employing three of the Falcon 9's Merlin engines to take about 50,000 kilograms (110,231 pounds) of mass into orbit. The ultimate goal of SpaceX is to make the rocket fully reusable. Their plan is to use rockets attached to each stage to carry out controlled ground landings and recover each component of the rocket. This has never been done before, but for good reason, as making a rocket that can survive the forces of re-entry intact is incredibly difficult.

Other innovations in the world of heavy-lift rockets have largely focused on new propulsive fuels and advanced technologies to make better use of what is already available. One example of this is NASA's new J-2X engine. The original J-2 engine was used on the Saturn V Moon rocket, the most powerful rocket of all time, but the new J-2X engine employs advanced capabilities to harness the power of this old workhorse and turn it into a modern marvel.

The only way for humans to venture beyond LEO, where the International Space Station (ISS) currently resides, is to use a heavy-lift rocket. NASA's long-term plan is to use its new Space Launch System to take astronauts first to the

Heavy lifting

How do giant rockets differ from the norm?

There are three major classes of rocket that are used to reach space. Light and medium launch vehicles are generally used for smaller satellite launches to LEO, whereas heavy-lift launch vehicles are used for deep-space missions and to haul larger objects into higher orbit. These rockets can do what others cannot, namely taking mega payloads into orbit. NASA's Saturn V rocket lifted an entire space station – the Skylab – in 1973.

One major benefit of heavy-lift rockets is the ability to lift a satellite to geostationary orbit. At this height – 35,406 kilometres (22,000 miles) above Earth – satellites stay in the same position, which is crucial for communications satellites. Heavy-lift rockets can also take vehicles, or even humans, to other planetary bodies. The Saturn V rocket could take 130 tons to Earth orbit or 50 tons to the Moon, and was imperative in the Apollo missions. NASA's next mega rocket, the Space Launch System, will be able to lift a comparable load and is planned to take astronauts to the Moon, an asteroid and Mars.

However, not all heavy-lift rockets can travel these large distances. NASA's Space Shuttle, although extremely powerful, did not have the propulsion to escape LEO, and thus it was used to take large payloads into orbit such as the Hubble Space Telescope and many modules for the ISS.

Inside NASA's Space Launch System

"One major benefit of heavy-lift rockets is the ability to lift a satellite to geostationary orbit"

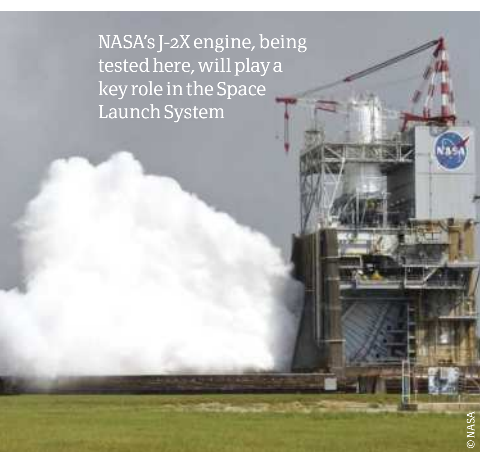
© NASA

Moon, then to an asteroid, and finally to Mars by the 2030s. SpaceX aims to challenge NASA's deep-space exploration plans by launching its own variant of the Falcon Heavy in the coming years. Known as the Red Dragon mission, this would see the soon-to-be completed Falcon Heavy taking a specially designed Dragon capsule, SpaceX's human transportation vehicle, to Mars by the 2020s. It all depends who finishes their heavy-lift launch vehicle first, but its entirely possible that the first human on Mars will be flown by a private technology company, which would be no small feat, to put it mildly.

Heavy-lift launch vehicles have a number of advantages over their smaller brethren, not least their size. Were it not for NASA's Space Transportation System rocket, used to take the Space Shuttle into orbit, the ISS would be some way from completion. It was thanks to the high operating capabilities of this launch system that NASA was able to contribute more than 90 per cent of the orbiting outpost and ensure that it reached completion in 2011.

Heavy-lift rockets, like regular-sized rockets, have a number of stages to take the vehicle into orbit. The first stage gets the rocket off the ground. This is usually composed of several booster rockets strapped together, like the Delta IV Heavy which uses three of the boosters seen on the smaller Delta III.

The advancement of launch vehicles promises to usher in an exciting era for space exploration. Bigger, more powerful rockets will enable us to visit once unreachable worlds. A human mission to Mars looks more and more likely, and as the rockets are developed further, the goal of landing humans on the Red Planet in the next decade or two might just be achievable.



NASA's J-2X engine, being tested here, will play a key role in the Space Launch System

© NASA

THE PAST

How man's most powerful rocket took astronauts to the Moon

The Saturn V is the most powerful rocket of all time… for the time being

© NASA

To date there has been no rocket that has matched, let alone exceeded, the lifting capabilities of the Saturn V Moon rocket. Of course, this will change in the future with the arrival of several new super-heavy-lift rockets, but for now the Saturn V retains the title of most powerful rocket of all time. Capable of lifting 130 tons into orbit, the Saturn V was used to take Apollo astronauts to the Moon throughout the Sixties and Seventies.

Undeniably the most well-known heavy-lift launch vehicle of all time, though, is the Space Transportation System (STS), used to take the Space Shuttle into orbit. The Space Shuttle could take a payload weighing 30 tons into orbit, and it was pivotal in the construction of the ISS. Now retired, the STS was one of the most powerful rockets of the modern era. It used solid rocket propellant and its initial rocket boosters were recoverable when they landed in the ocean, allowing for up to 20 more uses before they were deemed unsafe to fly.

THE PRESENT

The modern workhorses that launch satellites and resupply the ISS

Russia's heavy-lift Proton rocket is currently the longest-serving rocket in activity, completing its first flight in 1965. It has a formidable success rate: 88 per cent across over 300 launches. It has been one of the few successes of Russia's Space Program, which has otherwise been riddled with failures and a lack of advancement, particularly in missions beyond LEO.

Another hugely successful rocket has been Boeing's Delta series. The largest of these, the Delta IV Heavy, can take over 20 tons of cargo into orbit. The Delta IV Heavy uses two strap-on rocket boosters to achieve higher orbits and greater payload capabilities. In Europe, the ESA's Ariane 5 rocket continues to make great strides to being the most reliable heavy-lift rocket around. It uses a cryogenic main stage, holding liquid oxygen and hydrogen, to produce a thrust of 115 ton-forces, while two solid rocket boosters provide additional thrust. These heavy-lift vehicles have been instrumental in the modern space era and will continue to launch countless satellites and craft into the cosmos.

The Delta IV can take 21,772kg (48,000lb) of cargo into Low Earth Orbit (LEO)

© NASA

One of the huge boosters used on the Delta rockets

ROCKET SIZE COMPARISON

Saturn V
Manufacturer: NASA
Payload: 118,000kg
Operation: 1967-1972
Launches: 13

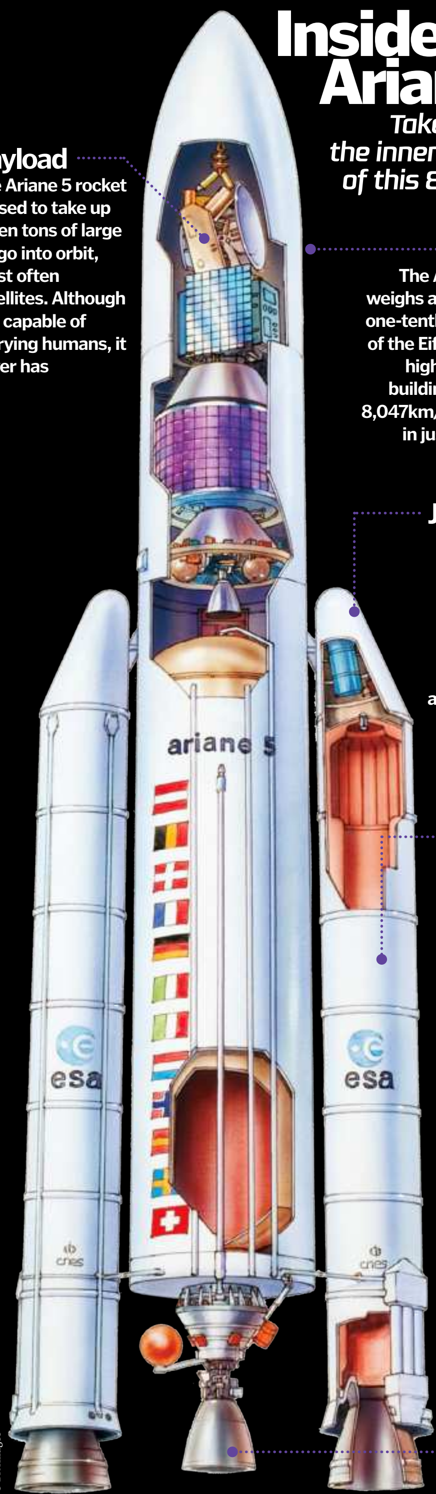
Space Transportation System
Manufacturer: NASA
Payload: 24,400kg
Operation: 1981-2011
Launches: 135

Delta IV Heavy
Manufacturer: United Launch Alliance
Payload: 22,950kg
Operation: 2004-present
Launches: 4

Titan IV
Manufacturer: Lockheed Martin
Payload: 21,682kg
Operation: 1989-2005
Launches: 35

Inside the Ariane 5

Take a look at the inner workings of this ESA rocket



Payload
The Ariane 5 rocket is used to take up to ten tons of large cargo into orbit, most often satellites. Although it is capable of carrying humans, it never has

Stats
The Ariane 5 rocket weighs about 700 tons, one-tenth of the weight of the Eiffel Tower, is as high as a 15-storey building and reaches 8,047km/h (5,000mph) in just 120 seconds

Jettisoned
Two or three minutes after launch the boosters are jettisoned to lighten the rocket and allow it to reach a high orbit

Booster
Inside each of the 30-metre (98-foot)-tall boosters is 230 tons of solid rocket propellant

Vulcan
The central Vulcan engine takes liquid propellant from the central cryogenic main stage to propel the payload out into space

© DK Images

© NASA

THE FUTURE

Which rockets will take us to the Red Planet and beyond?

With NASA's Space Shuttle retired in July 2011, the next step for the agency is to build a rocket comparable in size and power to the Saturn V. This comes in the form of the Space Launch System (SLS).

One of the major advancements of NASA's new mega rocket is its shift to liquid propellants over solid ones. Liquid propellants, while more expensive, allow for a greater power yield. In addition, solid propellants cannot be stopped burning when lit, a potential problem if a disaster were to occur, whereas liquid propellants can be throttled for the required speed. NASA is reusing old, tried-and-tested components to keep costs down. For example, the main booster core of the SLS will use five of the main engines that had been used to take the Space Shuttle into orbit. This booster core uses a liquid hydrogen/oxygen combination, a very efficient way of getting to orbit with minimal toxic waste produced. The second stage of the SLS will use a modified version of the engine used to take astronauts to the Moon aboard the Saturn V rocket. This will be the J-2X engine, an advancement of the old Saturn V J-2 engine. At first the SLS will be able to carry 70 tons to orbit, but eventually it will be able to handle 130 tons.

American manufacturer SpaceX is also making strides with heavy-lift rockets. Having already successfully flown the smaller Falcon 9 rocket, they plan to begin flying their Falcon Heavy in the coming years. With twice the payload capability of NASA's Space Shuttle, the Falcon Heavy promises trips to space at a fraction of the cost of current rockets.

It will use three Merlin engines – the Falcon 9 rocket only uses one – and with 1.7 million kilograms (3.8 million pounds) of thrust it will be equivalent to 15,747 jumbo jets operating at full power. The ultimate goal of SpaceX's Falcon Heavy is to make the rocket fully reusable. The company's plan is to use rockets attached to each stage to carry out controlled ground landings and recover each component. If successful, the Falcon Heavy will be one of the cheapest rockets to launch of all time.

Concept art of SpaceX's Falcon Heavy mega rocket

© SpaceX


The predecessor to the Falcon Heavy, the Falcon 9

© SpaceX


A visualisation of NASA's Space Launch System due to launch in November 2021

© NASA

Proton
Manufacturer: Roscosmos
Payload: 21,682kg
Operation: 1965-present
Launches: 326

Ariane 5
Manufacturer: EADS Astrium
Payload: 21,000kg
Operation: 1996-present
Launches: 56

Falcon Heavy
Manufacturer: SpaceX
Payload: 53,000kg
Operation: 2018-present
Launches: 0

Space Launch System
Manufacturer: NASA
Payload: 130,000kg
Operation: Due in 2021
Launches: 0

The Orion spacecraft

How the replacement for NASA's Space Shuttle will take us to the Moon and beyond

The primary goals of the Orion spacecraft, which has been contracted to technology company Lockheed Martin by NASA, are to deliver crew and cargo to the International Space Shuttle and return astronauts to the Moon after almost a 50-year wait. Orion made its first test flight in 2014 and is on course to complete a lunar mission by the early 2020s.

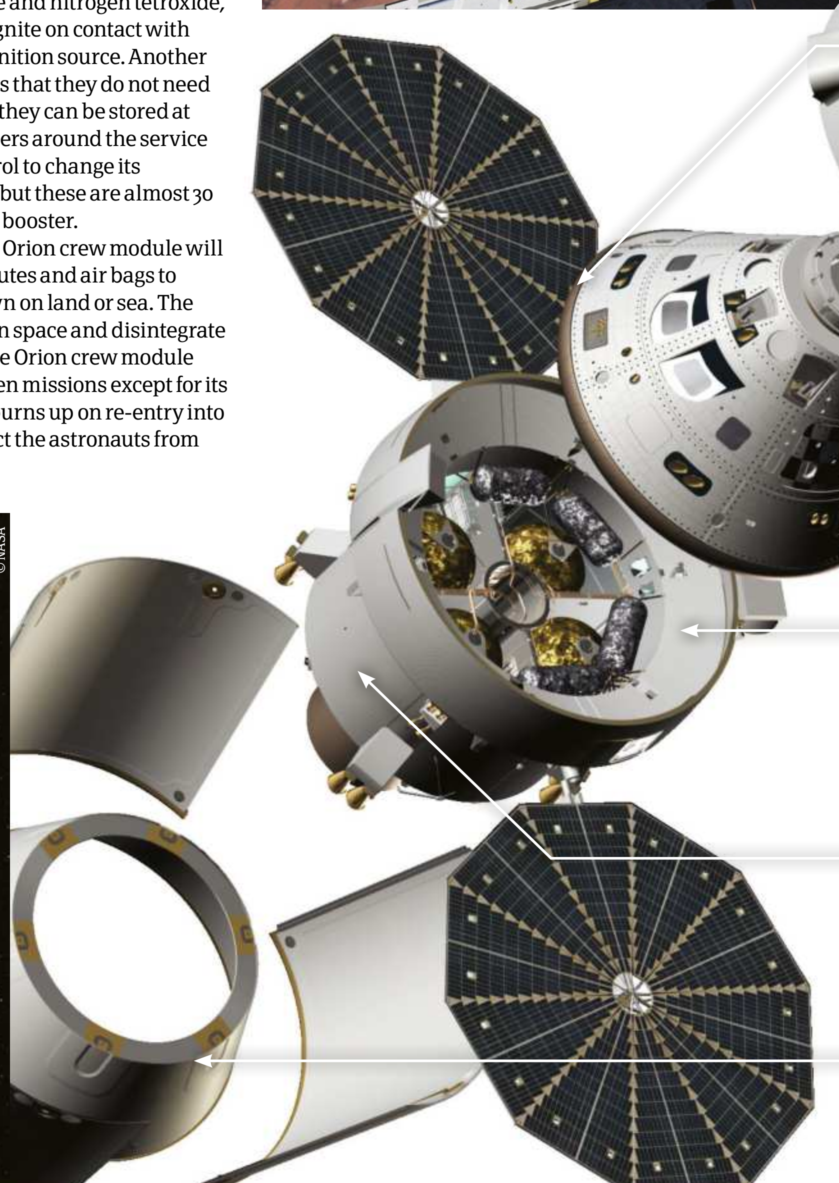
The Orion crew module is similar in design and appearance to the Apollo Command Module that first took astronauts to the Moon. It is three times the volume of the Apollo module with the same 70° sloped top, deemed to be the safest and most reliable shape for re-entering Earth's atmosphere at high velocity. The Orion module has a diameter of five metres and a total mass of about 9,000kg including the cargo and the crew, which increases or decreases slightly for missions to the International Space Station and the Moon respectively. Unlike the Apollo module, which had a crew capacity of three people, the Orion module can carry between four and six astronauts.

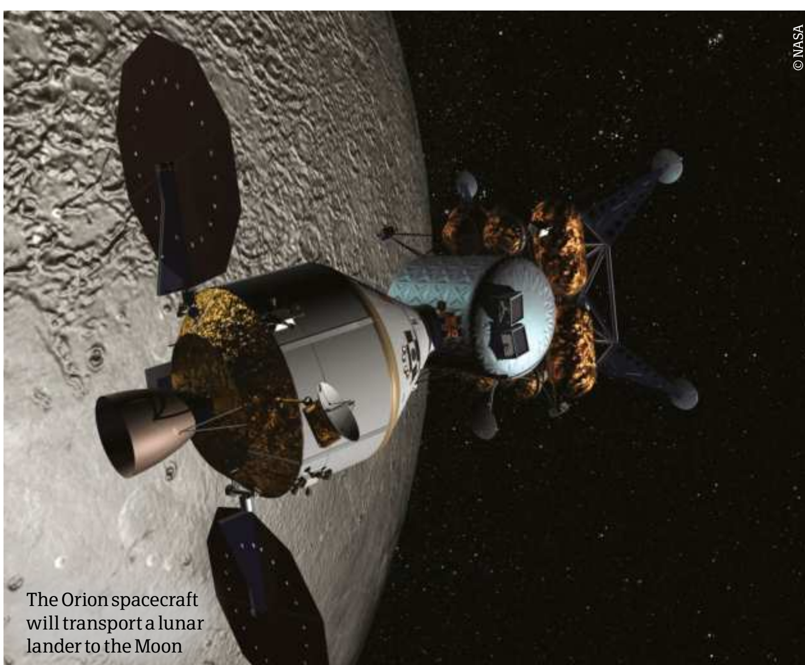
Attached to the crew module is the service module, responsible for propulsion, electrical power, communications and water/air storage. The service module is equipped with a pair of extendable solar panels that are deployed post-launch in addition to batteries to store power for times of darkness. Like the Orion crew module, the service module is also five metres in diameter to provide a clean fit between the two, and has a mass of about 3,700kg in addition to 8,300kg of propellant.

Exerting 33,000 newtons (7,500 pounds) of thrust, the engine of the service module uses hypergolic fuels monomethyl hydrazine and nitrogen tetroxide, which are propellants that ignite on contact with each other and require no ignition source. Another benefit of these propellants is that they do not need to be cooled like other fuels; they can be stored at room temperature. 24 thrusters around the service module will also give it control to change its orientation in all directions, but these are almost 30 times weaker than the main booster.

Upon descent to Earth the Orion crew module will use a combination of parachutes and air bags to allow a cushioned touchdown on land or sea. The service module will detach in space and disintegrate in the atmosphere. The entire Orion crew module will be reusable for at most ten missions except for its ablative heat shield, which burns up on re-entry into Earth's atmosphere to protect the astronauts from the extreme heat.


The first Orion missions will see it dock with the ISS to test its systems




The Orion spacecraft will transport a lunar lander to the Moon

Launch abort
In a launch pad emergency, this rocket will lift the crew module and allow it to parachute safely to ground

Heat shield
The ablative (burns on re-entry) heat shield protects the crew module as it returns to Earth alone before the parachutes deploy

Airlock
The top of the crew module allows docking with other vehicles such as the ISS and lunar landers

Crew module
Able to accommodate up to six crew members, this module provides a safe habitat for them to stay in during their journey

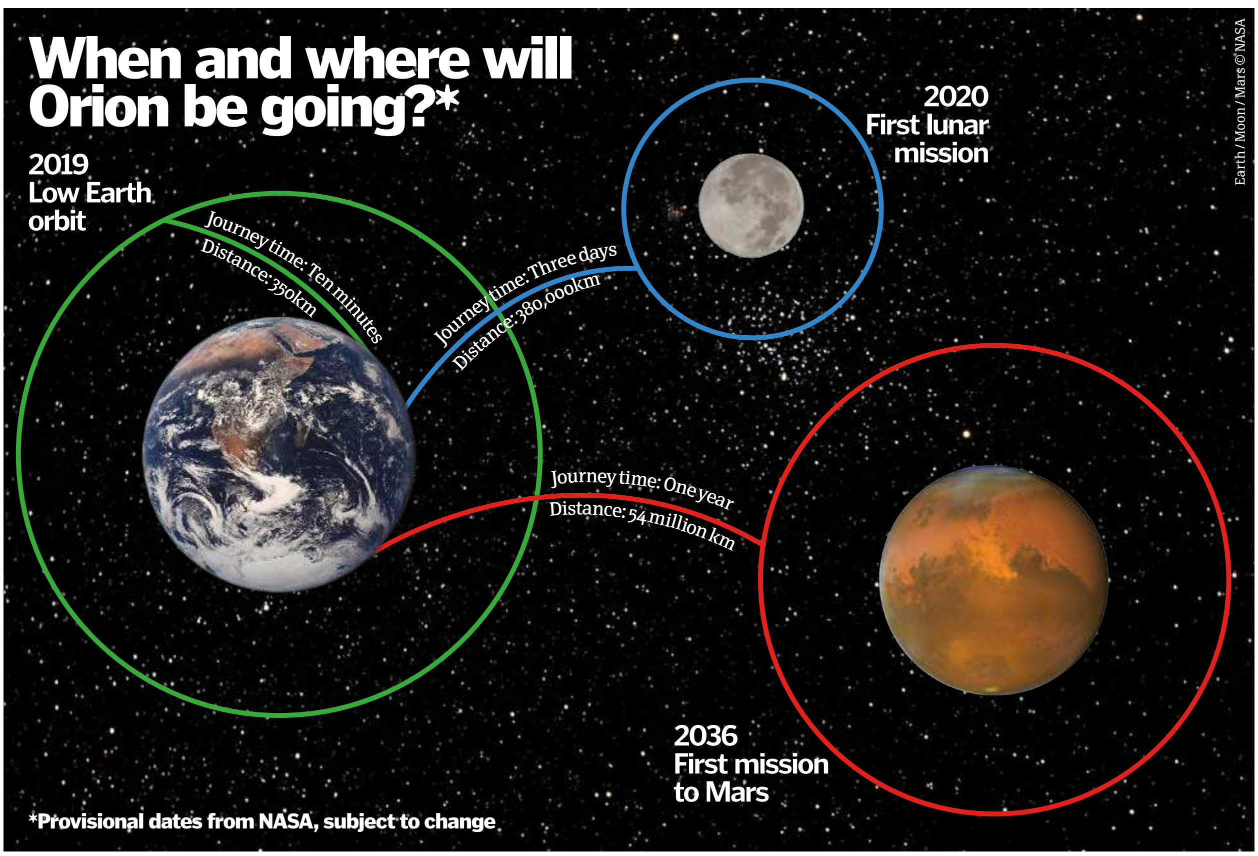
Service module
This module supports the crew throughout their journey, providing life support and propulsion, before detaching upon Earth re-entry

Cargo
Inside the service module, unpressurised cargo for the ISS and science equipment are stored

Spacecraft adapter
Connects the Orion spacecraft to the launch rocket, and also protects components in the service module

© NASA

The Launch Abort System will carry the crew module to safety in an emergency



SPACE TOURISM

Will we really be able to book a package holiday to space in the coming years?

Following the popularity and success of NASA's manned Apollo missions in the late 1960s, it seemed that space tourism would soon become a reality. Pan American Airways were quick to jump on the idea, opening a waiting list for a planned service to the Moon. Up until the company eventually disbanded in 1991, more than 93,000 wannabe astronauts had signed up for the scheme.

A new kind of space race was envisaged; private companies would compete to become the first to provide normal people with the chance to experience the wonders of space travel. It's incredible to think that in the years that followed Neil Armstrong's giant leap for mankind, only seven space tourists have made the trip to low-Earth orbit, none of which have even come close to retracing his famous footsteps on the lunar surface.

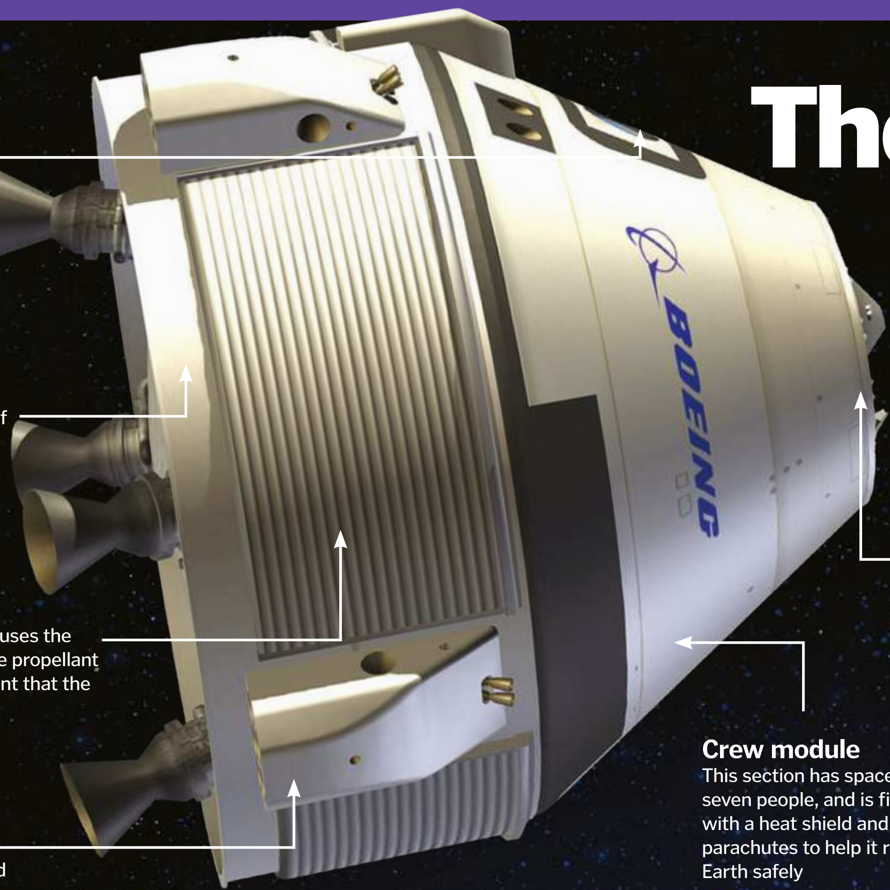
These individuals stayed on the International Space Station (ISS), and paid a considerable premium for the experience. The most recent, Canadian Guy Laliberté, coughed up an estimated £22 million ($35 million) for an 11-day trip in 2009. Although excursions to the ISS are hugely appealing, it is not designed to accommodate a tourist's needs. In spite of the ticket price, there are no luxuries; the ISS' sole purpose is to carry out vital research and support the astronauts on board.

All the space tourists used a version of the Russian Soyuz spacecraft to get to and from the ISS, but after the ISS' permanent crew was doubled to six members, this was no longer an option. This has galvanised a number of companies to explore alternative means of transporting paying passengers for short periods of time, such as space planes. The most talked-about space plane around is Virgin Galactic's SpaceShipTwo, which is lifted into the sky by a larger mothership, WhiteKnightTwo, before detaching and using its rocket engine to take a total of six passengers into space.

Once out of Earth's atmosphere, those on board will experience around five minutes of

The Boeing CST-100

Designed to carry crew and cargo to the ISS, the CST-100 could also transport space tourists



Forward window
This window enables restricted views out of the spacecraft, and is one of only three windows on the CST-100

Cost effective design
The outer layer of the spacecraft is composed of a weldless, honeycomb structure, helping keep weight and costs low

Service module
The large back section houses the rocket engines, carries the propellant and stores other equipment that the spacecraft may need

Reusable vessel
The CST-100 remains sturdy under pressure and can be used for a maximum of ten journeys before it needs to be replaced, keeping costs to a minimum

Autonomous docking system
Created for docking with the ISS or a potential future space station, the forward docking system is completely autonomous, reducing training time for potential crews

Crew module
This section has space for seven people, and is fitted with a heat shield and parachutes to help it return to Earth safely

Wi-Fi capability
The crew's communication system will feature tablet interfaces and wireless internet

Orbit	Launch vehicle	Height	Capsule diameter	First manned flight
Low-Earth orbit	Atlas V rocket	5.03m (16.5ft)	4.57m (15ft)	2017

SpaceX Dragon

First launch
2010

Three configurations
Cargo, crew and 'Dragon Lab'

Crew
Up to seven

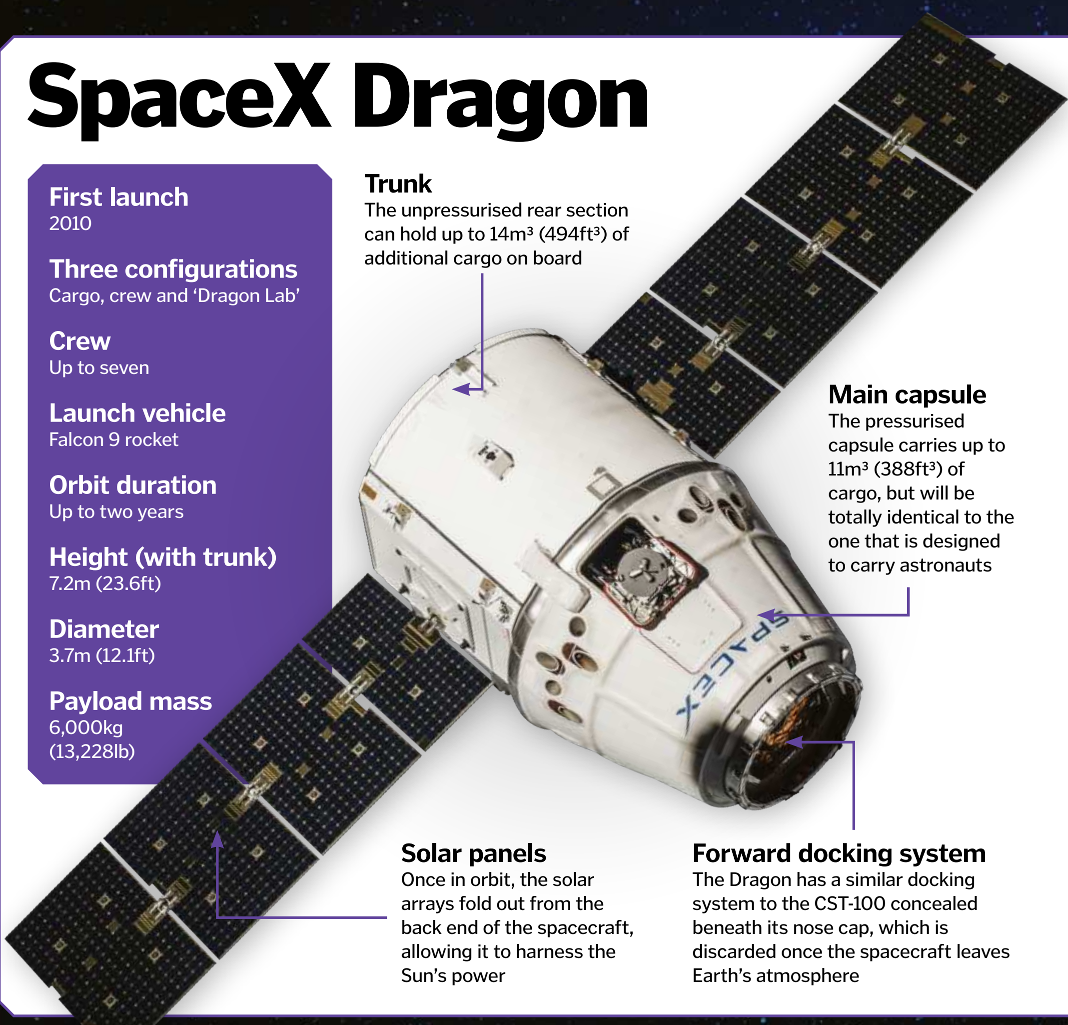
Launch vehicle
Falcon 9 rocket

Orbit duration
Up to two years

Height (with trunk)
7.2m (23.6ft)

Diameter
3.7m (12.1ft)

Payload mass
6,000kg (13,228lb)



Trunk
The unpressurised rear section can hold up to 14m³ (494ft³) of additional cargo on board

Main capsule
The pressurised capsule carries up to 11m³ (388ft³) of cargo, but will be totally identical to the one that is designed to carry astronauts

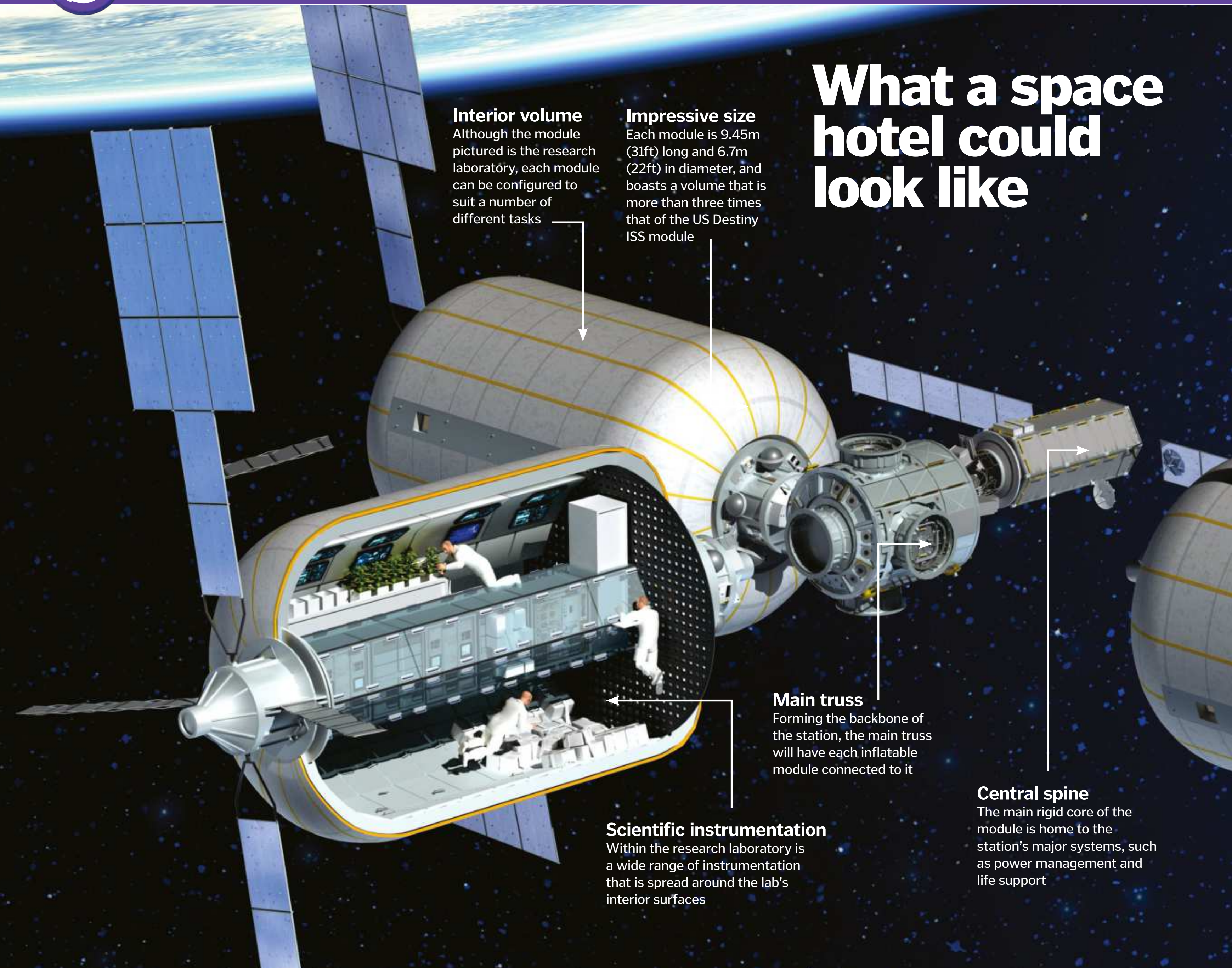
Solar panels
Once in orbit, the solar arrays fold out from the back end of the spacecraft, allowing it to harness the Sun's power

Forward docking system
The Dragon has a similar docking system to the CST-100 concealed beneath its nose cap, which is discarded once the spacecraft leaves Earth's atmosphere

The SpaceX Dragon has succeeded where many of its contemporaries have failed. In 2010 it became the first privately operated spacecraft to enter orbit, and was recovered after its record-breaking maiden voyage. Furthermore, the Dragon became the first commercial spacecraft to attach to the ISS. Due to this success, SpaceX signed a contract with NASA worth over £1 billion ($1.6 billion), representing a minimum of 12 cargo delivery flights to the ISS. SpaceX are currently developing the crew-carrying variant, the Dragon V2, which could eventually take both astronauts and tourists into orbit and beyond.

The first six unmanned runs to the ISS were a success. The seventh, which took off in June 2015, crashed back to Earth two minutes into the flight. After an investigation of the event, it is believed that a flawed steel strut that held a helium pressurisation bottle failed, resulting in an 'overpressure event' that destroyed the rocket. Where this leaves SpaceX is hard to say; they are still one of only a few companies to complete a space mission, yet this recent mishap may damage their chances of becoming the first private enterprise to partake in space tourism.

What a space hotel could look like



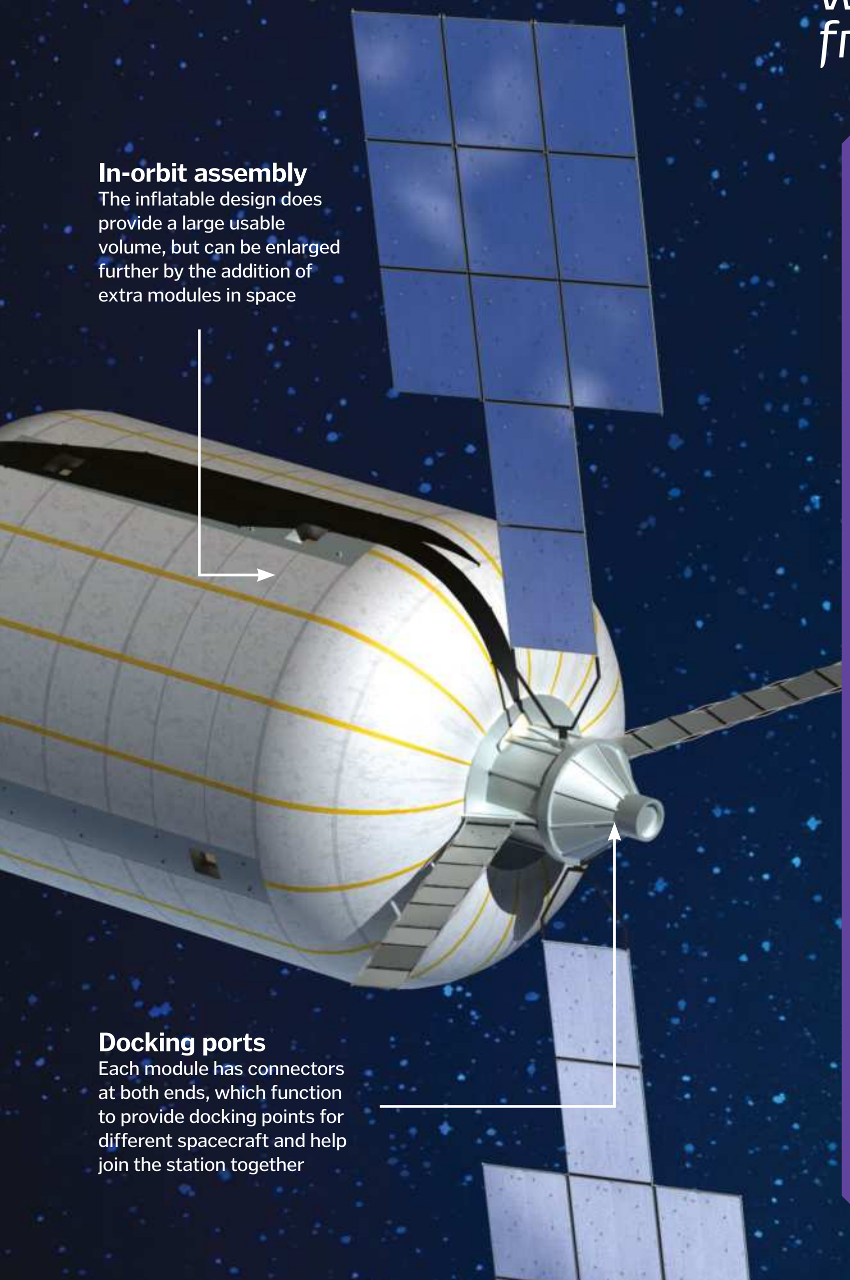
weightlessness, while gazing in wonder at the Earth's curvature and the surrounding stars. The tragic death of pilot Michael Alsbury during a test flight in 2014 has not deterred Virgin Galactic from reaching their goal, although it has meant that the first commercial flights have been further delayed. Whether or not this will form the foundation of space tourism is yet to be seen, but they do not offer a prolonged off-world stay. They also lack docking capabilities, which means they can't be used to whisk people away to any form of space hotel that may exist one day.

Aerospace company Boeing has taken a different tact. They have created a spacecraft that is likely to perform the first commercial flights, as part of a £2.7 billion ($4.2 billion) contract with NASA. The Crew Space Transportation-100, or CST-100 for short, has been tasked with this honour. Boeing and NASA hope that this spacecraft's first manned flight will take place in 2017, and once this has been completed, along with service flights to the ISS, the door will be open for commercial spaceflight.

The CST-100 is slightly larger than the Apollo Command Module and is being developed in cooperation with Bigelow Aerospace, as the capsule offers a means of reaching their planned space station in the future. As it is reusable, Boeing's spacecraft will be fitted with a combined recovery system featuring both parachutes and airbags, allowing it to land on the ground rather than in water when it returns to Earth. Reusability is key to its success, as the more times it can be used, the cheaper each flight will become for both the company and prospective customers.

If the future of space tourism doesn't involve staying on the ISS, there needs to be a new form of space station, which is where Bigelow Aerospace comes in. Their founder Robert Bigelow made his

"Despite having many of the necessary components in place, we are still a number of years away from space tourism taking off"



Life in space

Both of these products took their inspiration from NASA astronaut Donald Pettit, who tried to design a cup while in space

In spite of the many trials and tribulations it has experienced, space tourism is certainly going to happen. A number of companies have recognised the need for specific products in space; ones that are capable of overcoming the issues of microgravity.

One such company is the Cosmic Lifestyle Corporation, which has already designed a zero-gravity cocktail glass and coffee cup. Each glass is designed with a specific set of grooves that channel the liquid towards the mouthpiece. Without these grooves, the liquid would float out of the glass in sticky blobs which can scatter uncontrollably.

A space currency to pay for your Martinis may not yet exist, but as of 2014 there has been a way to pay for things in orbit. PayPal Galactic enables cashless payments to be carried out in space, and will even be capable of sending money back to Earth and vice versa. Although the cocktail glass isn't essential to our way of life, its technology will no doubt be seen more and more when space tourism takes off.

fortune building hotels, but he has been interested in space technology since childhood. Taking inspiration from NASA's 'TransHab' concept, Bigelow Aerospace plans to build its own inflatable space modules. It will use these to build private space stations, which it will operate and sell access to the public.

In 2006 and 2007, Bigelow launched Genesis 1 and 2 respectively, which were its first test craft to enter orbit. Since these launches the company has been relatively quiet, relying on ground testing while waiting for space tourism to grow as an industry. However, the BEAM (Bigelow Expandable Activity Module) is scheduled to launch later this year aboard a SpaceX Dragon capsule, and it will be connected to the ISS for two years to demonstrate its technology. Once this has been proven a success, the B330 will be launched. This has over 20 times the volume of the BEAM with 330 cubic metres (11,654 cubic feet) of internal space, and a proposed 20-year lifetime. Although its walls are inflatable, they will provide inhabitants with more protection from heat and radiation than the rigid ISS modules. Bigelow hopes that these modules will mark the beginning of vacations that truly are out of this world.

However, despite having many of the necessary components in place, we are still a number of years away from space tourism becoming a truly viable vacation option. It's more likely that trips to low-Earth orbit will become well-established first, before any form of 'hotel' opens for business. There is still so much that needs to be investigated before space travel can become feasible for the average person. Further research into the effects of remaining in space for long periods of time is vital, and it's hoped that NASA's ongoing Twins Study will provide some answers.

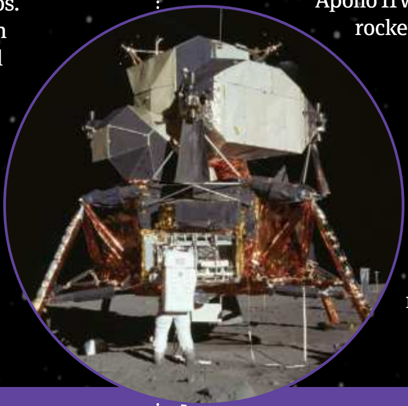
What is certain is that there will be plenty of adventurers packing their bags for a trip to infinity and beyond when the time comes.

SPACE TRAVEL

We take a look at the ten most important space missions of all time

Since Russia's Sputnik 1 satellite entered space on 4 October 1957, thousands of manned and unmanned spacecraft, including Earth satellites and deep-space probes, have launched into the cosmos.

In those five decades, space travel has truly come on leaps and bounds, with the development of liquid and solid fuels, as well as the use of solar panels and radioactive power sources among many of the impressive innovations, allowing space agencies across the planet to undertake evermore ambitious missions that would once have never been thought possible. Here, we've compiled ten of the most successful missions that have advanced the field of space travel to a whole new level.



1969

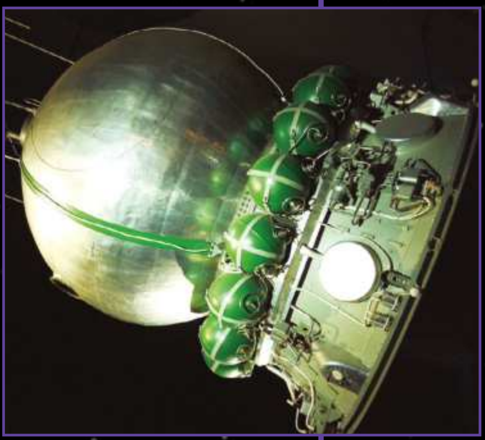
Apollo 11

Probably the most well-known space mission of all time, Apollo 11 was launched atop the most powerful rocket to date, the Saturn V. The spacecraft was composed of two sections – the Lunar Module and the Command Module – the latter of which remained in orbit around the Moon with Michael Collins on board while the former took astronauts Neil Armstrong and Buzz Aldrin to the surface. Apollo 11 paved the way for a further five successful missions to the Moon, each spending several days on the lunar surface.

1960s

1970s

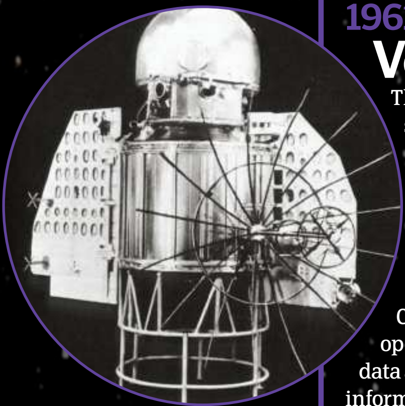
1980s



1961

Vostok 1

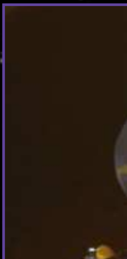
In 1961 Yuri Gagarin became the first man to travel to space, and the spacecraft that took him there for 68 minutes, was a fairly rudimentary sphere known as Vostok 1. As this was the first manned craft to leave Earth orbit, lots of extra precautions were taken, eg Gagarin was not able to freely move around the cabin, nor was he able to manually control the spacecraft. Nonetheless, in the timeline of space exploration, Vostok 1 is without a doubt one of the most important spacecraft of all time.



1961-1984

Venera probes

The Venera missions have been Russia's most successful space exploration missions to date. In total, 23 separate probes were launched to the hottest planet in our solar system, Venus, between 1961 and 1984, with ten of these landing on the surface. Each Venera lander was a technical marvel, withstanding incredible temperatures of up to 462 degrees Celsius (864 degrees Fahrenheit) to remain operational for up to two hours. They returned key data about the surface of Venus, including detailed information on the planet's atmospheric structure.



1977-present

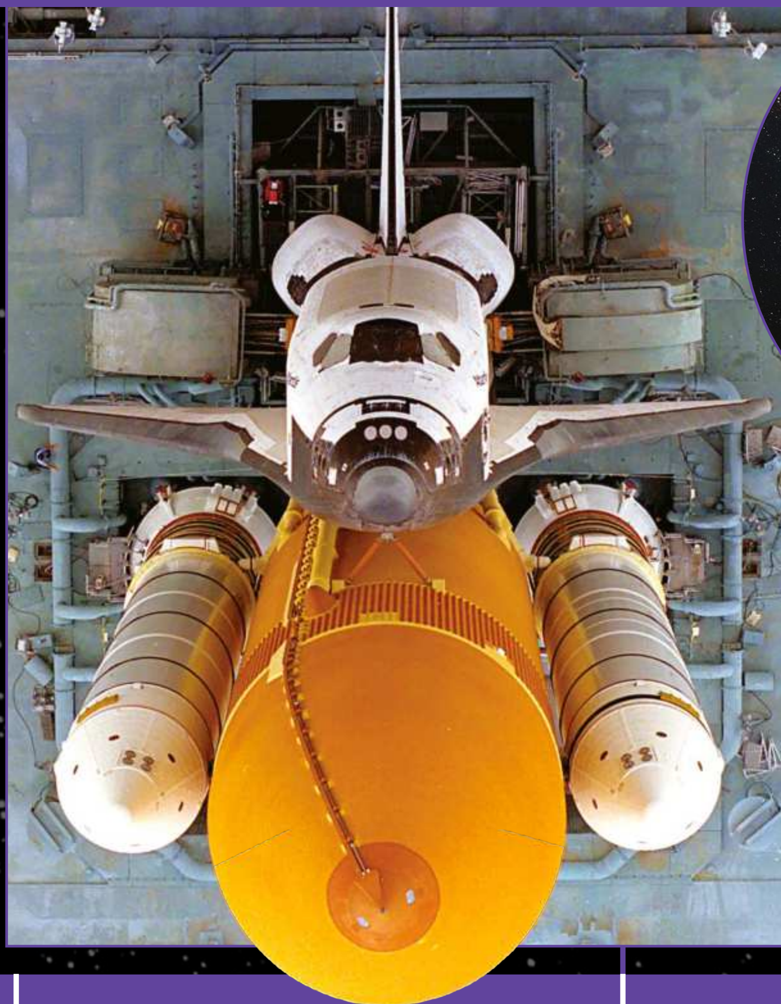
Voyager 1 and 2

The Voyager programme was originally designed to explore Jupiter, Saturn, Uranus and Neptune, but the mission was extended to include the boundary into interstellar space, which they are currently entering. The Voyager probes both receive power from three radioisotope thermoelectric generators, fed by plutonium-238. On board each probe is a variety of sounds and images known as the Golden Record, which also contains instructions on how to find Earth for any passing aliens.

1972-2003

Pioneer 10 and 11

The purpose of the Pioneer missions was to learn about the outer reaches of the solar system. These two spacecraft were, at the time of their launch, the most advanced vehicles to venture into space. They contained a number of technical tools never used before, including a charged particle instrument to measure the extent of the Sun's influence. While comms were lost in 1995 (Pioneer 11) and 2003 (Pioneer 10), the probes continue to make their way out of the solar system, with each possessing an on-board plaque detailing their origins.



1981-2011

Space Shuttles

NASA's five cosmos-faring Space Shuttles were the largest spacecraft of all time, and each completed numerous missions that defined them as some of the most important vehicles to enter Earth orbit. Their many accolades include taking the Hubble Space Telescope into orbit (and later repairing it) and launching more than 80 per cent of the modules for the ISS. There were 135 missions in total, but two of these ended in tragedy. The Challenger spacecraft exploded 73 seconds after launch in 1986, while in 2003 the Columbia spacecraft was torn apart on re-entry. While the Shuttles are remembered largely as a success, these two disasters serve as a reminder of just how dangerous space travel is.

2003-2010

Hayabusa

Japan's Hayabusa probe was the first spacecraft to return a sample from an asteroid, but it wasn't without its problems. A fuel leak rendered its chemical engines unusable and, coupled with a variety of mechanical failures, the probe was forced to limp home on its weaker ion engines. It eventually arrived three years behind schedule in 2010, but the mission was still a success. Ion engines on spacecraft have become more and more popular due to their longevity, rather than relying on an initial big 'push'.

1990s

2000s

1989-2003

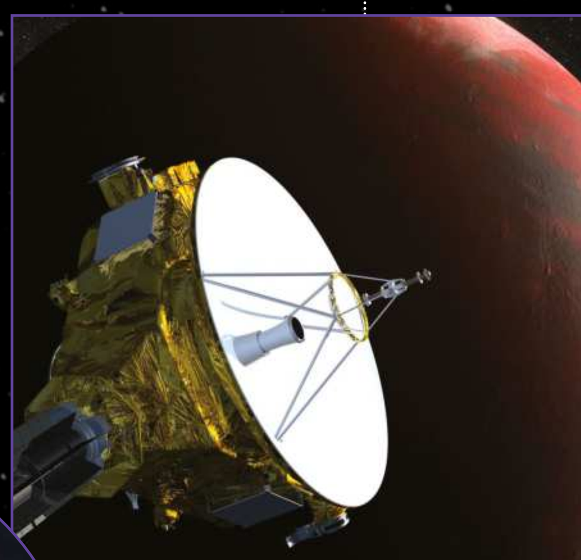
Galileo probe/ spacecraft

NASA's Galileo spacecraft was taken into space in 1989 and went on to study Jupiter after flybys of Venus and Earth. It was the first spacecraft to orbit Jupiter, in addition to performing the first flyby of an asteroid. It also carried the Galileo Space Probe, which it released into Jupiter's atmosphere in 1995, providing unprecedented data about the gas giant. In 2003 the orbiting spacecraft was sent crashing into our solar system's biggest planet to prevent it colliding with a nearby moon and causing contamination.

1997-2017

Cassini-Huygens

The Cassini-Huygens probe was a joint mission between NASA, the ESA and ASI (Italian Space Agency) and is often regarded as the most successful deep-space probe of all time. The orbiting component of the probe flew by Jupiter and became the first spacecraft to orbit Saturn. The landing vehicle was the Huygens Probe, which landed on Saturn's moon Titan in 2005, the first and only successful landing in the outer solar system. As with most probes, it is powered by plutonium-238, which enabled its mission to be extended to 2017. On 15 September 2017 it dived into Saturn's atmosphere and burned up.



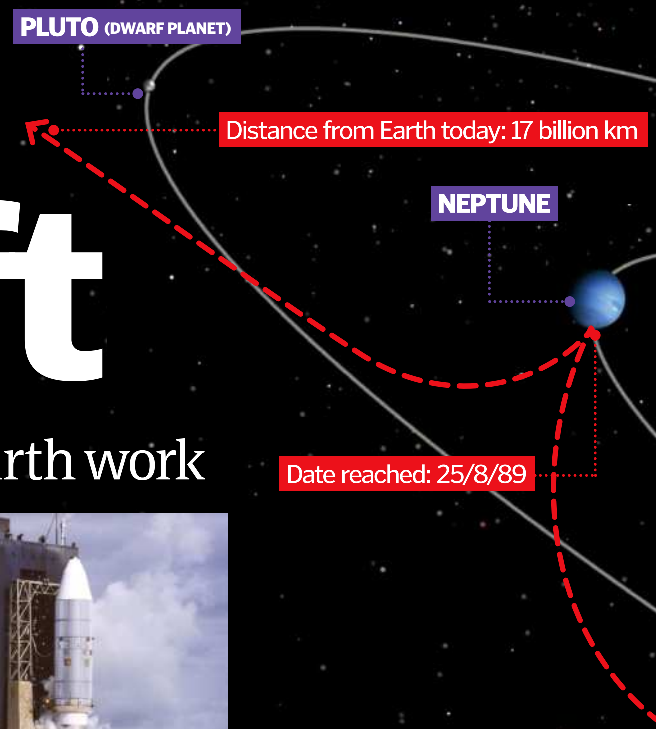
2006-present

New Horizons

NASA's New Horizons spacecraft became the first probe to fly by Pluto in 2015. While its primary mission is to study the (now) dwarf planet, it has also studied Jupiter and its moons. New Horizons is the fastest probe to have left Earth's orbit, and the first to be launched into a solar escape trajectory. It left Earth at 16.26 kilometers per second, faster than any spacecraft.

Voyager spacecraft

How the furthest man-made objects from Earth work



On 20 August 1977 Voyager 2 launched from Cape Canaveral in Florida aboard a Titan-Centaur rocket, heralding the start of one of the most ambitious deep space exploration missions of all time. Two weeks later Voyager 1 was sent up in an identical launch, although its greater speed meant that it eventually overtook Voyager 2. The list of accomplishments by the two probes is astounding. Between them they have studied all of the major planets of the solar system past Mars, in addition to some moons of Jupiter and Saturn, making countless new discoveries in the process. Now, as the furthest man-made objects from Earth, they are on their way out of the solar system.

The launch of the mission coincided with a favourable alignment of the planets in the Seventies that would allow Voyager 2 to visit Jupiter, Saturn, Uranus and Neptune. The list Voyager spacecraft achievements is extensive. The Voyager mission was only the second – after Pioneer 10 and 11 in 1974 and 1975, respectively – to visit Jupiter and then Saturn, but it also discovered the existence of rings around Jupiter, while Voyager 2 was the first mission to visit Uranus and Neptune.

The primary objective of the mission was to study Jupiter and Saturn, but once it became apparent that the spacecraft could continue working, the mission was extended to include Neptune and Uranus for Voyager 2. Voyager 1 could have travelled to Pluto, but NASA decided to extend its mission to Saturn and its moon Titan, leaving the dwarf planet Pluto one of the largest bodies in the solar system yet to be explored.

The Voyager probes obtain power from their radioactive generators, which have kept them running even at such a great distance from Earth and will continue to do so until about 2020, when they will no longer be able to power their instruments. Voyager 1 is roughly now over 17 billion kilometres (10.6 billion miles) from the Sun, while Voyager 2 is at a distance of over 14 billion kilometres (8.5 billion miles).

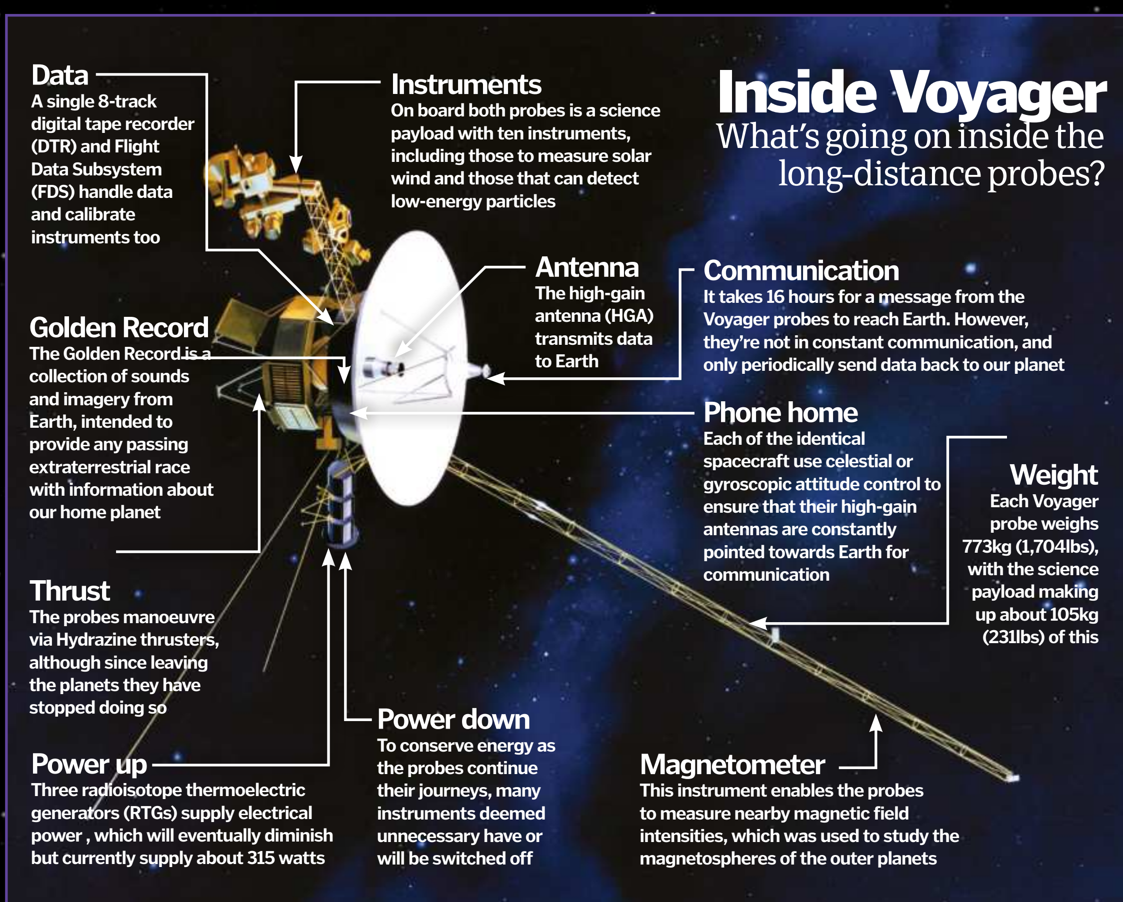
After making so many groundbreaking discoveries, both spacecraft are now on their way out of the solar system. They are both expected to pass out of the Sun's influence and into interstellar space in the coming years, although it is not entirely clear when this will happen as no machine has yet experienced the conditions that the Voyager probes are about to endure.

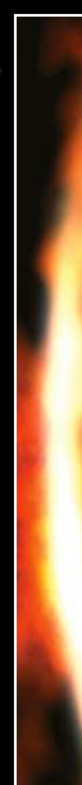
In 40,000 years, Voyager 1 should be within 1.6 light years (9.4 trillion miles) of a star in the constellation of Camelopardalis thought to harbour a planetary system. 256,000 years later, Voyager 2 will be 4.3light years (25 trillion miles) from Sirius, which is the brightest star other than the Sun in our own night sky.


Voyager 2 launched atop a Titan III-Centaur rocket on 20 August 1977

Inside Voyager

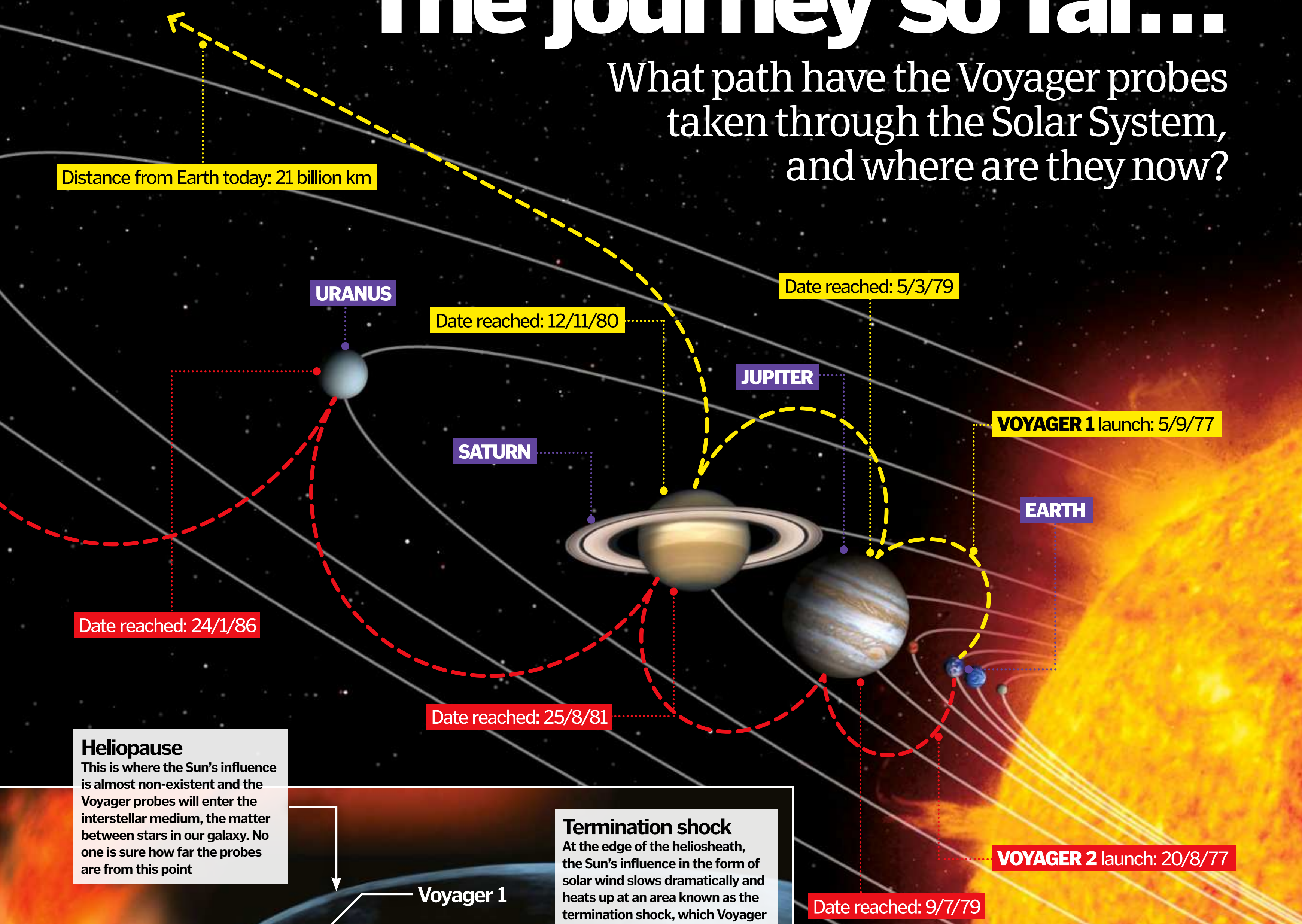
What's going on inside the long-distance probes?



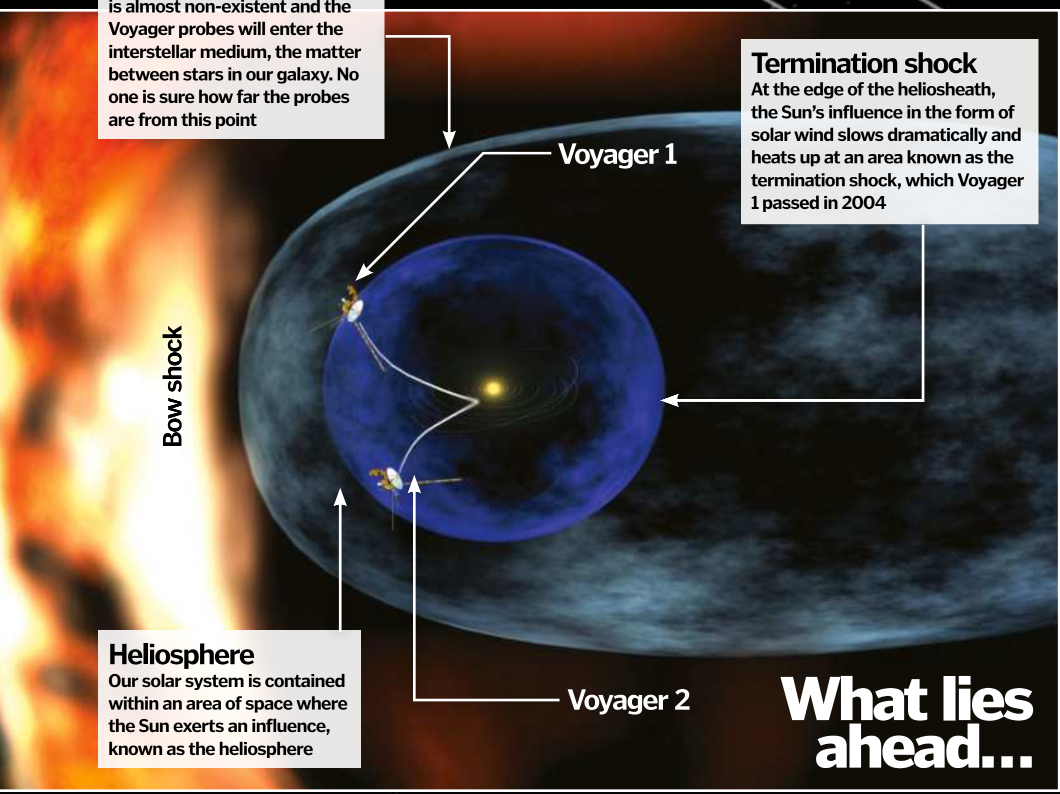


The journey so far…

What path have the Voyager probes taken through the Solar System, and where are they now?



What lies ahead…

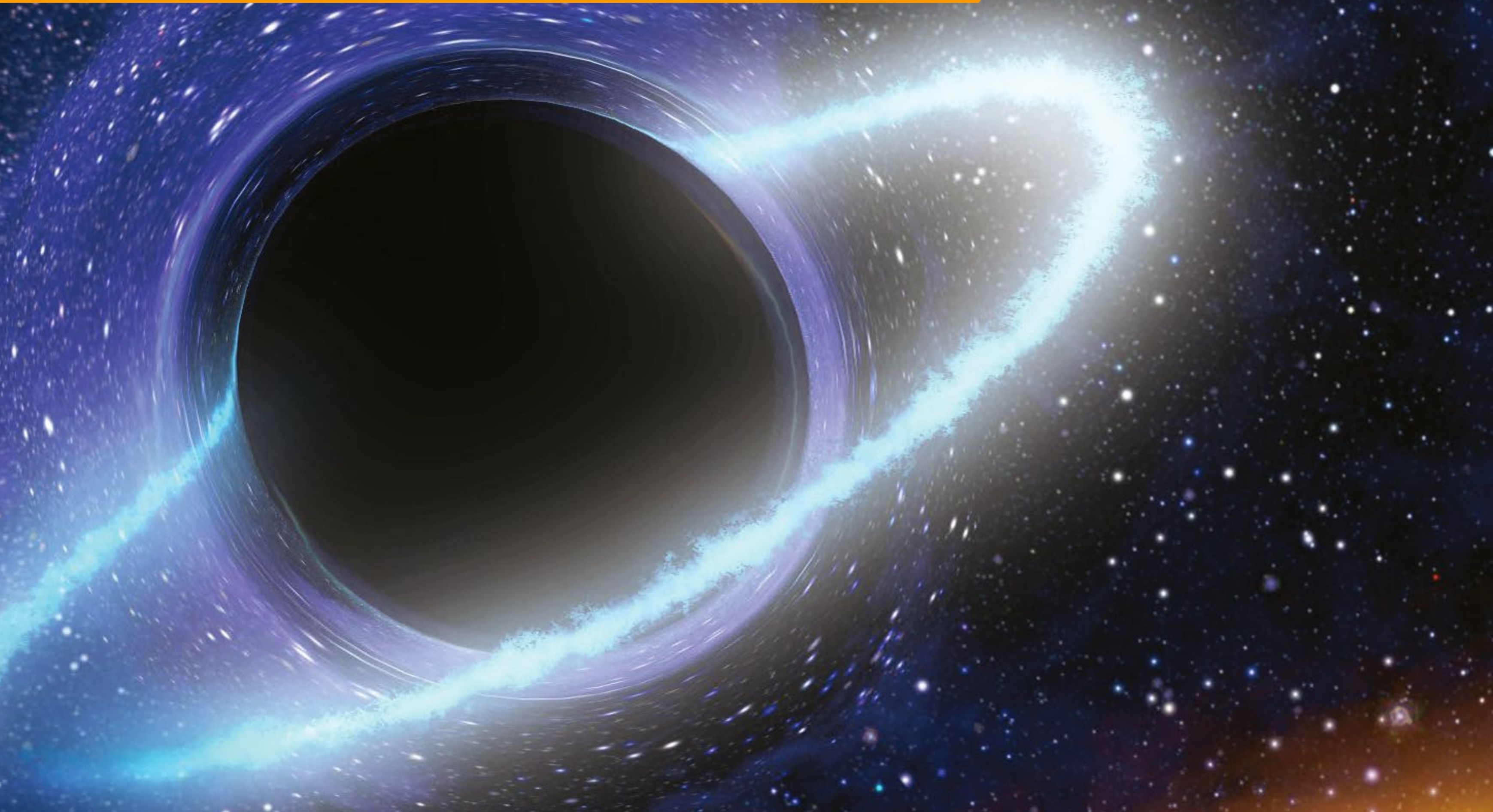


Heliopause
This is where the Sun's influence is almost non-existent and the Voyager probes will enter the interstellar medium, the matter between stars in our galaxy. No one is sure how far the probes are from this point

Termination shock
At the edge of the heliosheath, the Sun's influence in the form of solar wind slows dramatically and heats up at an area known as the termination shock, which Voyager 1 passed in 2004

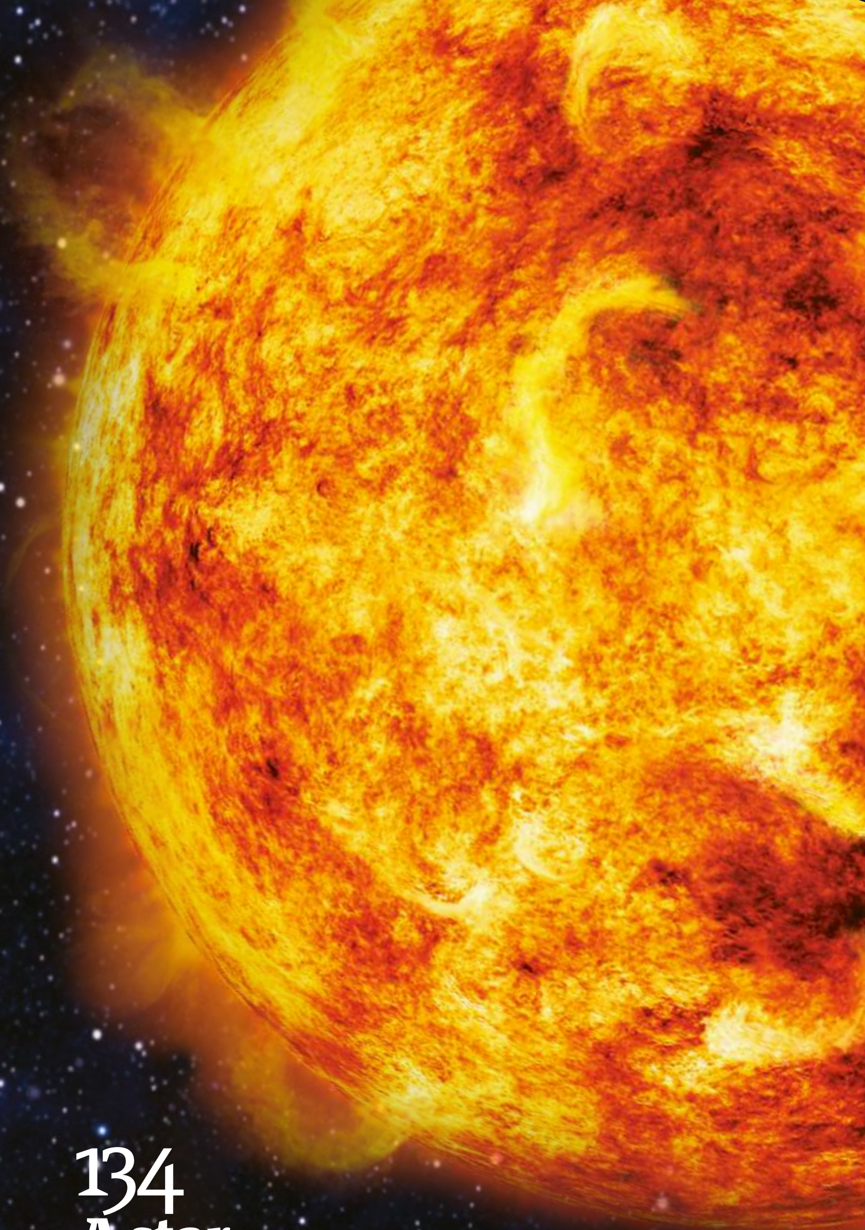
Heliosphere
Our solar system is contained within an area of space where the Sun exerts an influence, known as the heliosphere

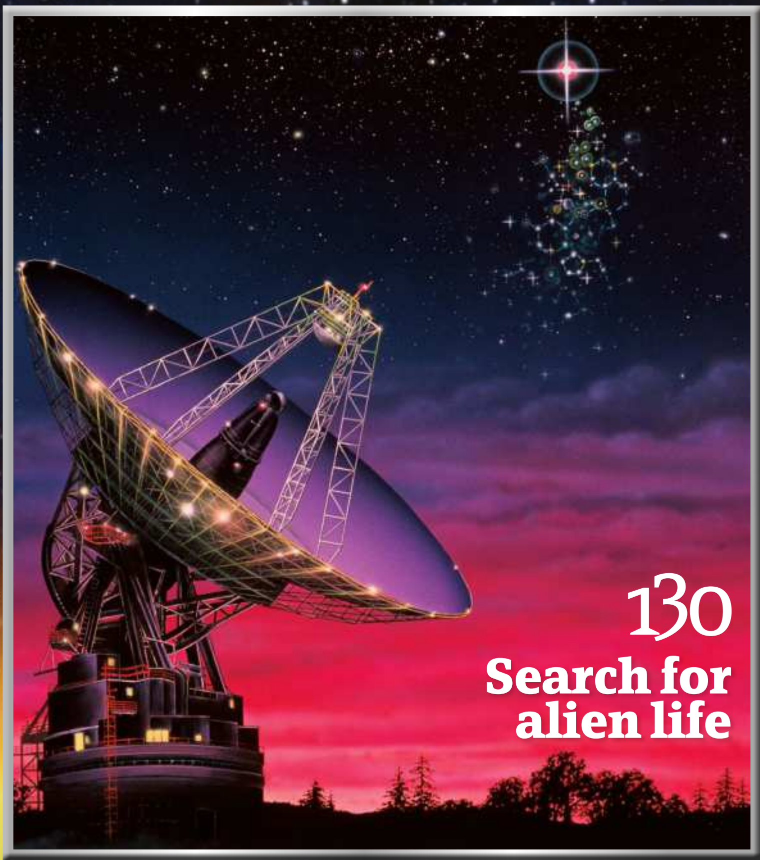
On 16 November 1980, Voyager 1 looked back at Saturn and snapped this picture four days after it had passed the planet



126
Supernovas

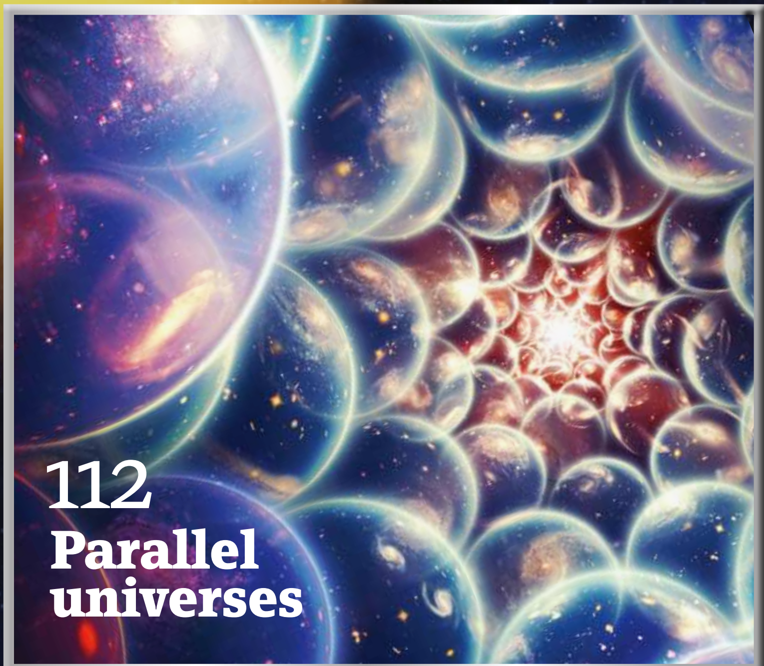
"We will drive forward our understanding of space"





130 **Search for alien life**

134 **A star is born**



112 **Parallel universes**

134 **A-Z of the galaxy**

10 secrets of space

Our universe is full of odd phenomena that we don't yet fully understand – here we look at the science of the most intriguing

Answering questions and solving puzzles has been the driving force behind astronomy for thousands of years, even if it often seems that for every mystery solved, a new one springs up. Today, astronomers like to think they have a fairly good understanding of the way our universe works, and processes from the life cycle of stars to the evolution of galaxies, and it's certainly true that we know a lot more than we did a century ago. But there are still plenty of loose ends and new ones are still constantly emerging.

Some of these mysteries are recent discoveries that may seem at first to break the established rules. Of course, we can't be sure until these particular enigmas are resolved, but often the solution to puzzles like this is just a matter of time; once a mystery object such as the 'impossible star' SDSS J102915+172927 or the rectangular galaxy LEDA 074886 is announced to the world, scientists can turn their collective efforts and a huge array of observational techniques to learning more about it and understanding why it defies convention.

Others require more patience – for instance, new images of Uranus's satellite Miranda would certainly reveal more about its turbulent history, but we're sadly unlikely to be sending another probe that way any time soon. The long-standing mysteries of the Sun's corona have had to await the development of new techniques for studying it. And the ins and outs of 'dark matter' that permeates the entire cosmos still remain frustratingly elusive.

But perhaps the most exciting mysteries of all are those that come completely out of the blue, such as the dark energy accelerating the expansion of the universe. Two decades ago, astronomers didn't even know there was a puzzle to be solved, yet now dark energy is one of the hottest topics in the field. It's discoveries like this and 'unknown unknowns' that will doubtless be discovered in the future that help drive forward our understanding of not just space, but also our place within it.

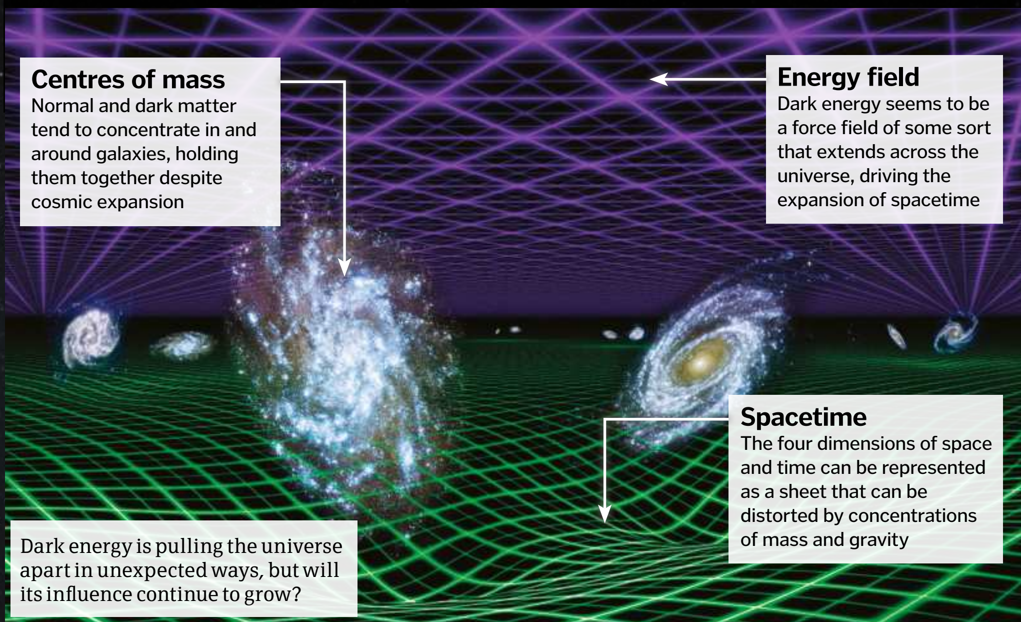
1. Most of the universe is missing

For the past decade, astronomers have been getting to grips with a mystery that has undermined a lot of what we previously thought we knew about the cosmos. We once thought the universe was dominated by two substances: normal, or 'baryonic', matter (matter that interacts with light and other forms of radiation), and invisible 'dark' matter that is transparent to light and only makes its presence felt through gravity (see Mystery 8).

But in the late-Nineties, cosmologists found an unexpected twist: the expansion of the universe (which should be slowing down due to the gravitational drag of the matter within it) is speeding up. The evidence for this comes from distant supernova explosions in galaxies billions of light years from Earth, which appear fainter than we would expect if we relied on previous models of cosmic expansion.

The phenomenon responsible is called 'dark energy' and seems to account for a staggering 70 per cent of the universe. Nobody knows exactly what dark energy is, but perhaps the most intriguing – and even alarming – aspect to the discovery is that it seems to be increasing. Until around 7.5 billion years ago, expansion was slowing; then the strength of dark energy overcame gravity and the expansion picked up again.

If the growth of dark energy continues, some predict that the universe might end in a 'Big Rip' many billions of years from now, when it becomes so powerful that galaxies, stars and even individual particles of matter are torn apart.



Dark energy is pulling the universe apart in unexpected ways, but will its influence continue to grow?

2. The origin of cosmic rays

Cosmic rays are high-speed, high-energy particles from space, which we usually detect via the less energetic particles they produce as they enter Earth's upper atmosphere. Astronomers divide them into several classes depending on their speed and energy, and most seem to originate from distant supernovas. Perhaps the most troublesome, however, are the ultra-high-energy rays – tiny subatomic particles that can carry the same amount of energy as a baseball travelling at 100 kilometres (62 miles) per hour.

For some years, the likeliest origin for ultra-high-energy particles seemed to be gamma-ray bursts (GRBs) – enormous blasts of energy linked to dying stars or merging black holes. But recent studies using the IceCube Neutrino Observatory, a particle detector buried beneath Antarctica, failed to find the predicted neutrino particles that would indicate this origin. Astronomers are now revisiting the idea that they are formed by natural particle accelerators around supermassive black holes in the heart of distant active galaxies.

If exploding stars or colliding black holes can't create high-energy cosmic rays, astronomers need to find something even more powerful…

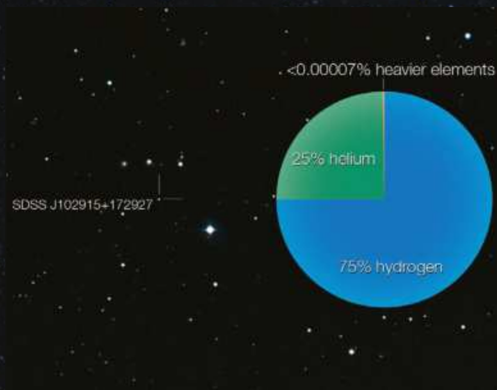
3. Impossible stars

Occasionally, astronomers come across a star that seems to break all the rules and forces them to rethink long-cherished theories. In 2011, scientists at the European Southern Observatory (ESO) made one such discovery in the form of SDSS J102915+172927 (Caffau's star) – a star roughly 4,000 light years from Earth in the constellation of Leo.

This star has about four-fifths the mass of our Sun, and is composed mainly of hydrogen and helium, the two lightest elements in the universe. Together, they make up around 99.99993 per cent of its entire composition, with heavier elements – known as metals – almost entirely absent.

Such a pure lightweight star must have formed more than 13 billion years ago from the raw cosmic materials remaining after the Big Bang, but the problem is that according to accepted models of star formation it shouldn't have ever been born.

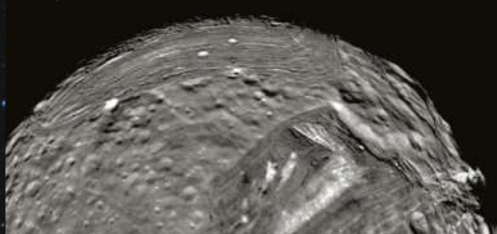
In order to produce enough gravity to collapse and form a star, astronomers believe a protostellar cloud needs either to have a significant amount of heavier metals or a larger overall mass – small, low-density stars simply shouldn't exist.

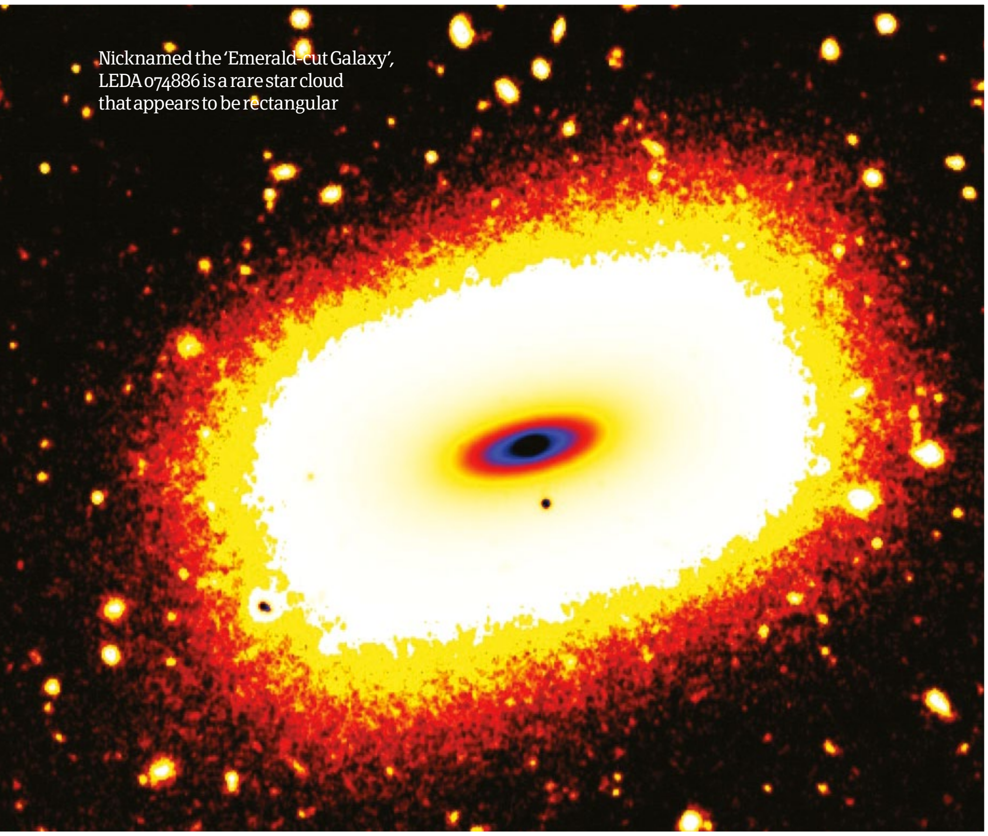


4. The moon that shouldn't exist

When Voyager 2 flew past Uranus in 1986, its close-up views of the ringed planet's inner satellite Miranda surprised everyone. This small 470-kilometre (292-mile)-diameter moon shows a huge variety of different surface features that seem to break the rule that smaller worlds don't show geological activity. Astronomers soon nicknamed it the 'Frankenstein moon', since it looks like it has been broken up and reassembled, perhaps in some ancient interplanetary impact. But there's a problem with this theory: Miranda's orbit is too close to Uranus for it to have pulled itself together again after breaking up. Instead, some scientists think it was reshaped by extreme tides.

Miranda's patchwork appearance is evidence of a turbulent past, but did it really break apart and reform?



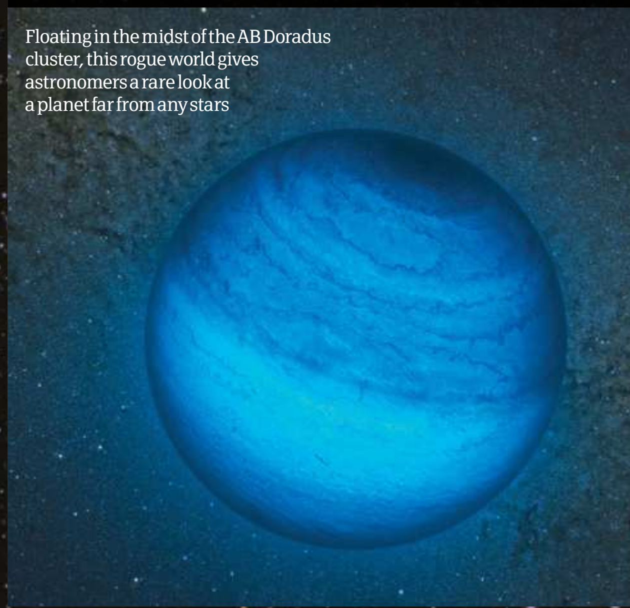

Nicknamed the 'Emerald-cut Galaxy', LEDA 074886 is a rare star cloud that appears to be rectangular

5. Rectangular galaxies

The laws of orbital mechanics mean that stars always follow elliptical (stretched circular) orbits when influenced by gravity, so in large groups they form either flattened disc-like spirals or ball-shaped ellipticals. The corners of a rectangle should be impossible, but astronomers have found several galaxies with apparently rectangular features. For example, LEDA 074886 in the constellation of Eridanus is a compact, rectangular galaxy within a nearby galaxy cluster. The big question is whether its shape is a long-lived structure or brief coincidence. Astronomers who studied it with the giant Japanese Subaru telescope think the latter is more likely, and a collision and merger between two could have scattered outlying stars into the box-like distribution, triggering starbirth at the new centre.

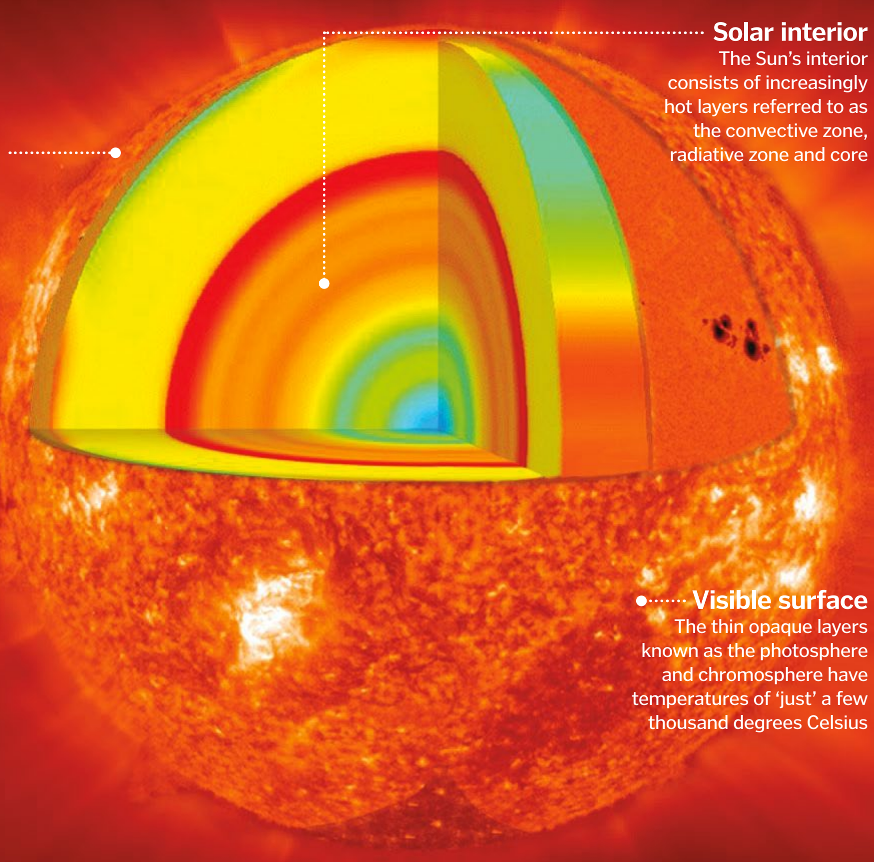
6. The rogue planet

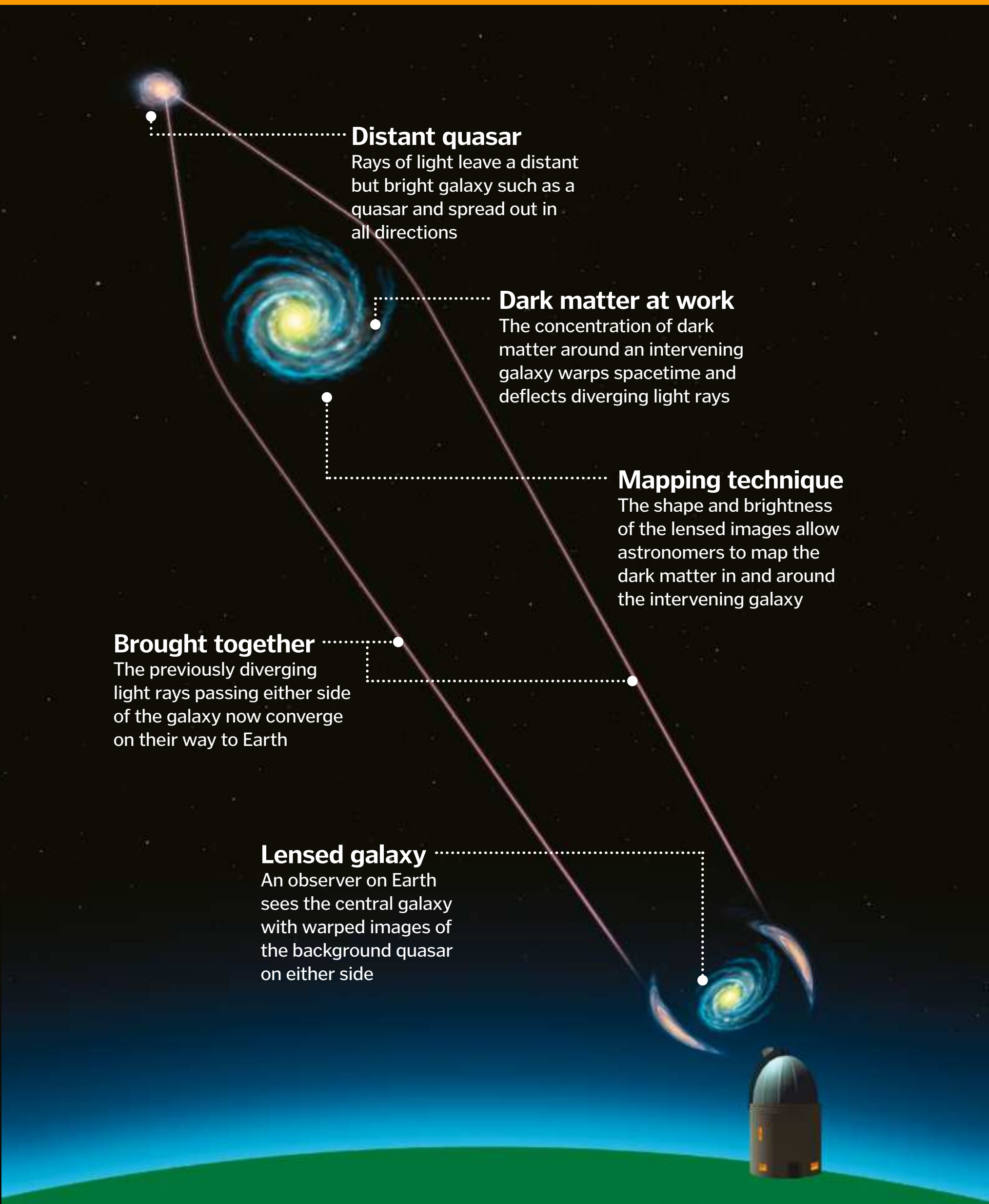
According to the standard definition, a planet is a substantial object in orbit around a star, formed from the debris left behind in the aftermath of starbirth. So how do some planets end up floating alone through the galaxy, far from any stars? Astronomers have discovered several of these, of which the closest and most intriguing goes by the catalogue name of CFBDSIR J214947.2-040308.9. First spotted in 2012, this rogue planet sits about 100 light years away in the AB Doradus Moving Group – a cluster of young stars. With a surface temperature of around 400 degrees Celsius (752 degrees Fahrenheit), it is probably a gas giant much heavier than Jupiter, either still warm from the events of its formation, or perhaps with its own internal energy source driven by gravitational contraction. Too far from a star to shine by reflected light, the planet was only detected due to the infrared glow from its surface. As with all rogue planets, astronomers aren't sure if it started life orbiting a star before being flung off into space (perhaps in a close encounter with another star), or if it formed independently from the same nebula as the surrounding cluster, making it a 'sub-brown dwarf star'.


Floating in the midst of the AB Doradus cluster, this rogue world gives astronomers a rare look at a planet far from any stars

7. The Sun's corona shouldn't be hotter than its surface

The Sun's visible surface is one of its coolest regions, with an average temperature of around 5,800 degrees Celsius (10,472 degrees Fahrenheit). But while it's no surprise that temperatures towards the core rise to around 15 million degrees Celsius (27 million degrees Fahrenheit), the fact that the Sun's thin outer atmosphere, known as the corona, rapidly soars to more than 2 million degrees Celsius (3.6 million degrees Fahrenheit) is more puzzling. This huge rise in temperature takes place across a 'transition region' less than 1,000 kilometres (621 miles) deep, and solar physicists still aren't sure what drives it. The leading contenders are shocks caused by sound waves rippling across the surface, and 'nanoflares' – bursts of energy released by changes to the Sun's magnetic field. New imaging technology on board NASA's Solar Dynamics Observatory (SDO) mission is helping map these phenomena in unprecedented detail, and may soon provide definitive answers to this enigma.





8. The quest to find dark matter

Since the Thirties, astronomers have understood that there's a lot more to the universe than just the material we can see. Normal – or baryonic – matter can't help but interact with light and other forms of electromagnetic radiation – stars emit visible light, hot gas emits X-rays, and even the coldest material in the universe emits radio waves and infrared, and clouds made up of this type of matter also absorb radiation that passes through them.

But there's another class of matter that ignores light completely – so-called 'dark matter' that is not just dark but entirely transparent to all types of radiation. It gives itself away only through its gravitational influence on visible objects around it – for example, affecting the orbits of stars within galaxies and galaxies within galaxy clusters. More recently, astronomers have also developed techniques to map the distribution of dark matter through 'gravitational lensing' – the way in which large concentrations of matter deflect the passage of nearby light waves.

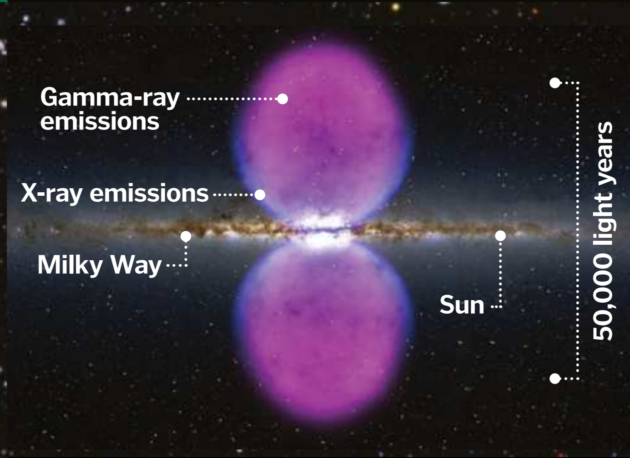
Evidence suggests that dark matter outweighs visible matter by roughly six to one. But what is it made of? Astronomers used to think that 'massive compact halo objects', or MACHOs – normal matter in forms too dark and faint to detect, such as lone planets and black holes – might make a contribution, but as our telescopes have improved, it's become clear that these objects don't exist in sufficient quantities. Instead, cosmologists now believe dark matter consists largely of 'weakly interactive massive particles', or WIMPs – exotic subatomic particles that don't interact with radiation or normal matter, but possess considerable mass. But what exactly WIMPs are is still to be worked out.

Astronomers can map the distribution of dark matter across the universe, but it's more likely they'll discover its true nature via particle experiments closer to home

9. Unpredictable pulsars

Pulsars are supposed to be the most reliable timekeepers in the universe. These collapsed neutron stars (the super-dense cores of once-massive stars that long ago destroyed themselves in supernovas) channel intense beams of radiation into space along their powerful magnetic fields, creating a 'cosmic lighthouse' that appears to switch on and off many times each second from our point of view on Earth. Most pulsars emit either X-rays, radio waves, or both, but in early-2013 astronomers discovered a pulsar known as PSR B0943+10 emitting both radio and X-ray wavelengths, changing from one type of radiation to the other in seconds. This behaviour could be due to 'starquakes' on the neutron star's surface, which astronomers believe can also cause glitches when a pulsar's period changes speed, or due to strange activity around the pulsar.

PSR B0943+10 is a rare pulsar that alternates between beaming out radio waves and X-rays



10. Galactic bubbles

Two bubbles of superhot gas, some 25,000 light years in diameter, extend above and below our Milky Way. Found in 2010 via the Fermi Gamma-ray Space Telescope, the 'Fermi bubbles' are some of the largest structures in our part of the universe, but how did they form? The bubbles have sharp edges and are hollow inside, suggesting expansion from a single-event, perhaps millions of years ago.

One theory is that they are remnants of shockwaves generated when the centre of our galaxy underwent a burst of star formation followed by a wave of supernovas. Another is that they were ejected by activity in our central supermassive black hole.

The Big Bang

As an elegant explanation of the origins of both atoms and galaxies, the Big Bang is the ultimate theory of everything

The Big Bang theory begins with a simple assumption: if the universe is expanding and cooling – something Edwin Hubble and company proved at the beginning of the 20th Century – then it must have once been very small and very hot. From then on, the simple becomes infinitely complex. Big Bang theory is nothing less than the summation of everything we've learned about the very big (astrophysics) and the very small (quantum physics) in the history of human thought.

Cosmologists – people who study the origin and evolution of the universe – theorise that 13.7 billion years ago, a bubble formed out of the void. The bubble, many times smaller than a single proton, contained all matter and radiation in our current universe. Propelled by a mysterious outward force, the bubble instantaneously expanded (it didn't explode) by a factor of 1,027, triggering a cosmic domino effect that created the stars, the galaxies and life as we know it.

The Planck era Time: Zero to 10^{-43} seconds

The Planck era describes the impossibly short passage of time between the absolute beginning of the universe (zero) and 10^{-43} seconds (10 trillionths of a yoctosecond, if you're counting). In this fraction of an instant, the universe went from infinite density to something called Planck density (1093g/cm3), the equivalent of 100 billion galaxies squeezed into the nucleus of an atom. Beyond the Planck density, rules of General Relativity don't apply, so the very dawn of time is still a complete and utter mystery.

ERA

TIME

Inflation era

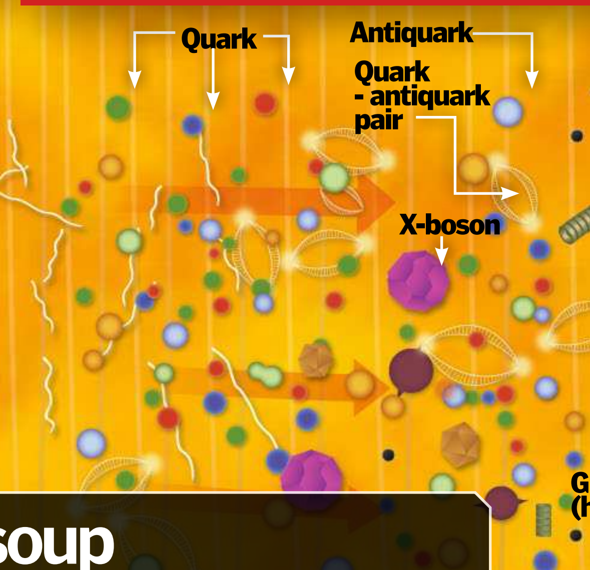
10^{-36} to 10^{-32} after Big Bang

In the Eighties, cosmologists theorised a period of spontaneous expansion in the very early moments of time. Instantaneously, every point in the universe expanded by a factor of 1,027. The universe didn't get bigger, it just was bigger. Because the universe got so big, so fast, its naturally spherical shape appeared flat to objects on the surface, solving one of the early problems with Big Bang theory.

Quark era

10^{-32} to 10^{-12}

After the explosive inflation period, the universe was a dense cauldron of pure energy. Under these conditions, gamma rays of energy collided to briefly form quarks and anti-quarks, the fundamental building blocks of matter. Just as quickly, though, the quarks and anti-quarks collided in a process called annihilation, converting their mass back to pure energy.



Particle soup

If you turn the heat up high enough, everything melts. When the universe was 10-32 seconds old, it burned at a magnificent 1,000 trillion trillion degrees Celsius. At this remarkable temperature, the tiniest building blocks of matter – quarks and anti-quarks, leptons and anti-leptons – swirled freely in a particle soup called the quark-gluon plasma. Gluon is the invisible 'glue' that carries the strong force, binding quarks into protons and neutrons.

Let there be light

The primordial soup of the early universe was composed of pairs of particles and anti-particles (mostly quarks, anti-quarks, leptons and anti-leptons). Picture this ultra-hot, supercharged environment as the original super collider. Particles and anti-particles smashed together in a process called annihilation, producing beams of photons (light radiation). As more particles collided, more light was generated. Some of those photons reformed into particles, but when the universe finally cooled enough to form stable atoms, the spare photons were set free. The net result: the (observable) universe contains a billion times more light than it does matter.

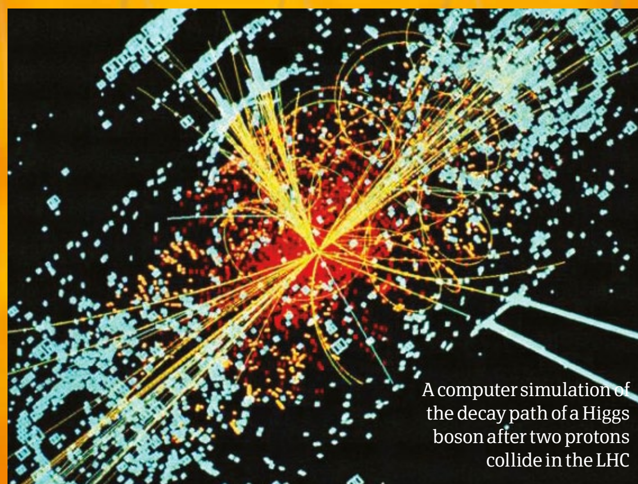
X-bosons

A funny thing happened at 10^{-39} seconds after the beginning of time. The universe produced huge particles called X-bosons (1,015 times more massive than protons). X-bosons are neither matter nor anti-matter and exist only to carry the Grand Unified Force, a combination of the electromagnetic, weak and strong forces that exist today.

The Grand Unified Force drove the early expansion of the universe, but rapid cooling caused X-bosons to decay into protons and anti-protons. For reasons that aren't clear, a billion and one protons were created for every billion anti-protons, creating a tiny net gain of matter. This imbalance, forged during a short blip in time, is the reason for our matter-dominated universe.

Recreating the Big Bang

CERN's Large Hadron Collider (LHC) is the world's largest particle accelerator. At full power, trillions of protons travel at near light speed through super-cooled vacuum tubes buried 100 metres below the surface. As the protons smash into each other – at a rate of 600 million collisions per second – they generate energy 100,000 times hotter than the Sun, a faithful recreation of the cosmic conditions milliseconds after the Big Bang. Using ultra-sensitive detectors, scientists scoured the debris trails for traces of quarks, leptons and the Higgs boson, proving the existence of the previously hypothetical particle that gives mass to matter.

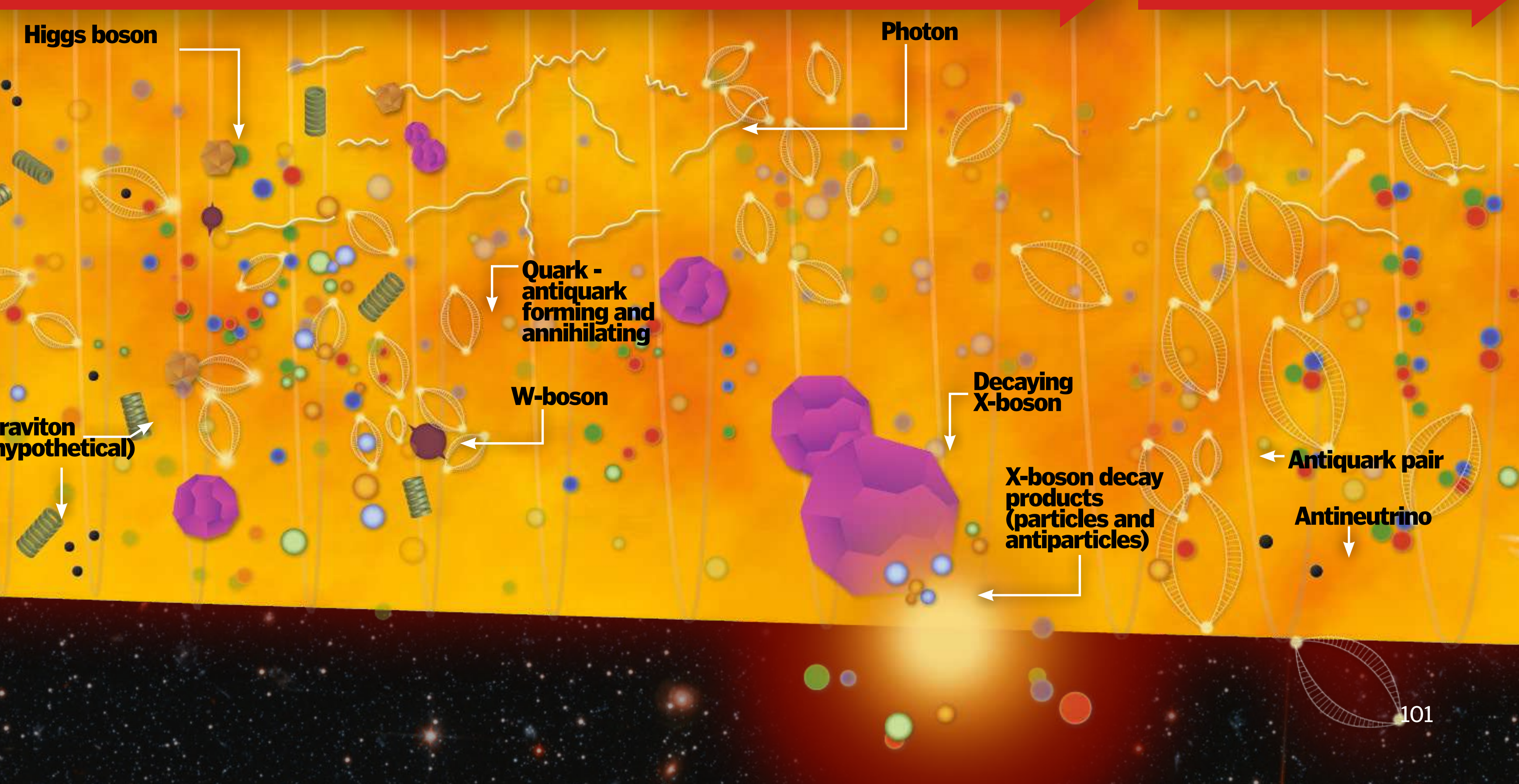


A computer simulation of the decay path of a Higgs boson after two protons collide in the LHC

Separation of the Electroweak force

During the Planck era, the four forces of nature were briefly unified: gravity, the strong force, electromagnetism and the weak force. As the Planck era ended as the universe cooled, gravity separated out, then the strong force separated during the inflation. But it wasn't until the end of the Quark era that the universe was cool enough to separate the electromagnetic and weak forces, establishing the physical laws we follow today.

110^{-9} to 10^{-62}



The origins of matter

Everything in the universe – the galaxies, the stars, the planets, even your big toe – is made of matter. In the beginning (roughly 13.7 billion years ago), matter and radiation were bound together in a superheated, super-dense fog. As the universe cooled and expanded, the first elemental particles emerged: quarks and anti-quarks. As things cooled further, the strong force separated, pulling together clumps of quarks into protons and neutrons, building the first atomic nuclei. Half a million years later, conditions were finally cool enough for nuclei to pull in free electrons, forming the first stable atoms. Small fluctuations in the density of matter distribution led to clusters and clouds of matter that coalesced, over hundreds of millions of years, into the stars and galaxies we explore today.

Dark forces

So what is the universe made of? Well, there is more to the universe than meets the eye. Cosmologists have proven that the visible or 'luminous' portions of the cosmos – the stars, galaxies, quasars and planets – are only a small fraction of the total mass and composition of the universe. Using super-accurate measurements of cosmic microwave background radiation fluctuations, scientists estimate that only 4.6 per cent of the universe is composed of atoms (baryonic matter), 23 per cent is dark matter (invisible and undetectable, but with a gravitational effect on baryonic matter), and 72 per cent is dark energy, a bizarre form of matter that works in opposition to gravity. Many cosmologists believe that dark energy is responsible for the accelerating expansion of the universe, which should be contracting under its own gravitational pull.

Hadron era

When the expanding universe cooled to 1,013K (ten quadrillion degrees Celsius), quarks became stable enough to bond together through the strong force. When three quarks clump together in the right formation, they form hadrons, a type of particle that includes protons and neutrons. Miraculously, every single proton and neutron in the known universe was created during this millisecond of time.

Lepton era

During this comparatively 'long' era, the rapidly expanding universe cools to 109K, allowing for the formation of a new kind of particle called a lepton. Leptons, like quarks, are the near mass-less building blocks of matter. Electrons are a 'flavour' of lepton, as are neutrinos.

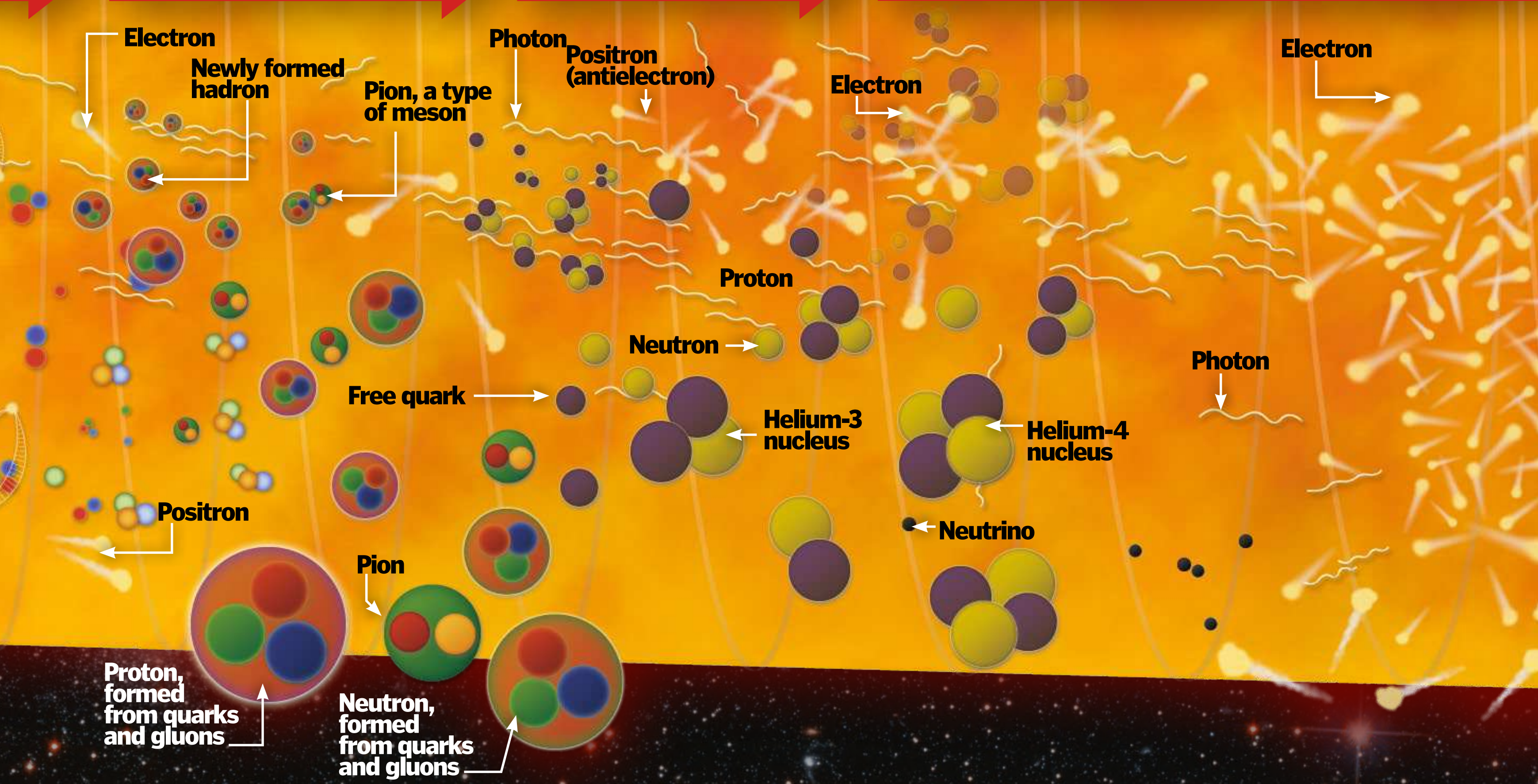
Nucleosynthesis era

For 17 glorious minutes, the universe reached the ideal temperature to support nuclear fusion, the process by which protons and neutrons bond together to form atomic nuclei. Only the lightest elements have time to form – 75 per cent hydrogen, 25 per cent helium – before fusion winds down.

10^{-6} to 1 second

1 second to 3 minutes

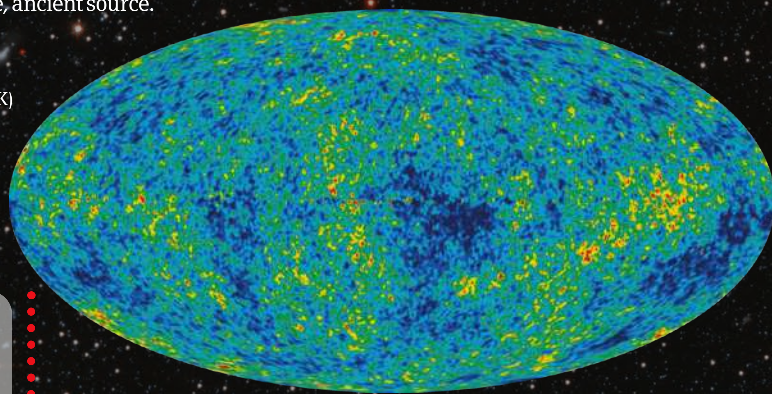
3 minutes to 20 minutes



Cosmic microwave background radiation

The residual heat from the big bang can give us a clue to the origin of the universe

As the universe expands, it also cools. The inconceivable heat released during the Big Bang has been slowly dissipating as the universe continues its 14 billion-year expansion. Using sensitive satellite equipment, cosmologists can measure the residual heat from the Big Bang, which exists as cosmic microwave background radiation (CMBR). CMBR is everywhere in the known universe and its temperature is nearly constant (a nippy 2.725K over absolute zero), further proof that the radiation emanated from a single, ancient source.



Minute differences in microwave background radiation levels (+/- 0.0002K) reveal fluctuations in the density of matter in the primitive universe

Opaque era

These are the 'dark ages' of the universe, when light and matter were intertwined in a dense cosmic fog. Photons of light collided constantly with free protons (hydrogen ions), neutrons, electrons and helium nuclei, trapping the light in a thick plasma of particles. It is impossible for cosmologists to 'see' beyond this era, since there is no visible light.

Balance of elements

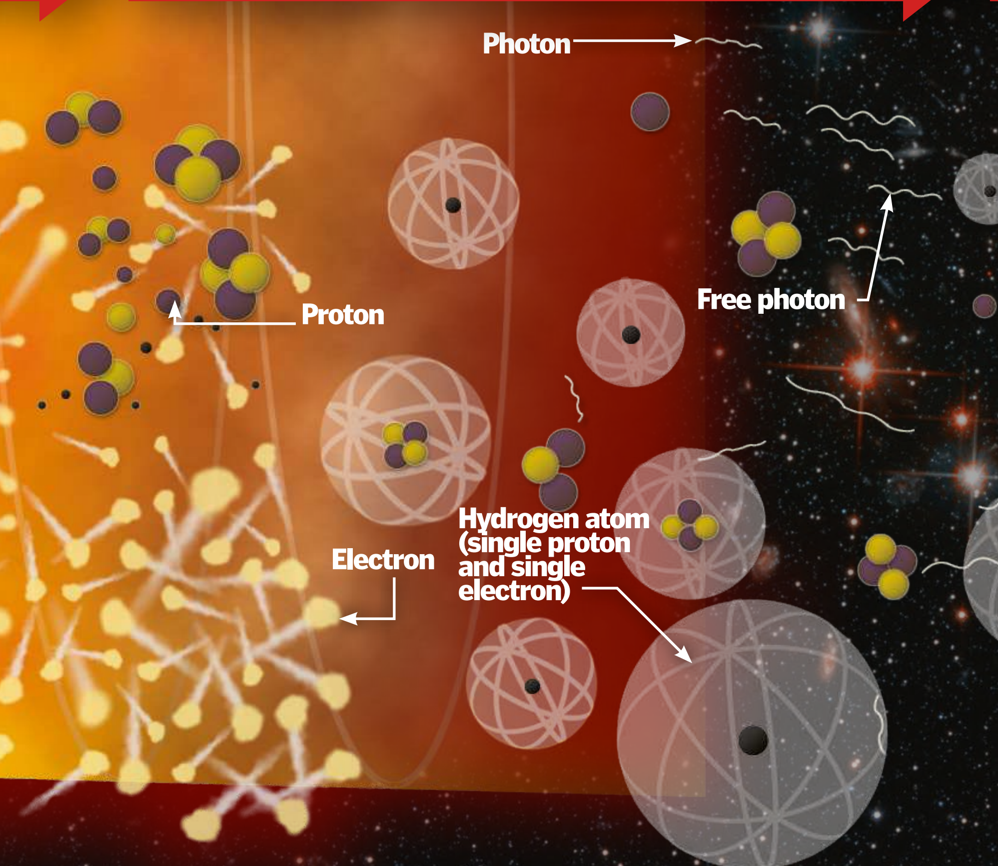
When the temperature dropped to 10,000K, electrons slowed down enough to be pulled into orbit around atomic nuclei, forming the first stable, neutral atoms of hydrogen, helium and other trace elements. As atoms started to form, photons were freed from the cosmic fog, creating a transparent universe. All cosmic background radiation originated with this 'last scattering' of photons.

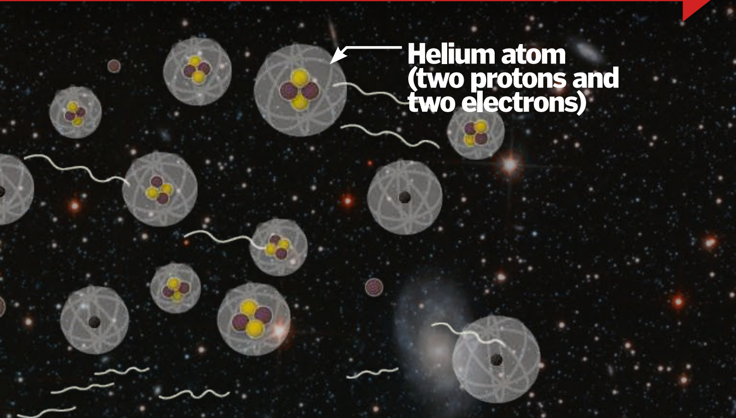
Matter era

During the Opaque era, matter and light were stuck together as plasma. Photons of light applied radiation pressure on matter, preventing it from bonding together to form atoms and larger particles. When light and matter 'decoupled', the radiation pressure was released as light, freeing matter to clump and collect in the first clouds of interstellar gas. From there, the first stars were born around 400 million years after the Big Bang.

20 minutes to 377,000 years

500,000 to the present





The 'God' particle

We take for granted the idea that if something is made of protons, neutrons and electrons, then it inherently has mass. But cosmologists now believe that no particle has mass simply by merit of its existence. Instead, mass is bestowed on particles as they pass through a Higgs field, a quantum field named after British physicist Peter Higgs. Imagine the Higgs field as a bowl of honey and quantum particles as a string of pearls. As you drag the pearls through the honey, they are imbued with mass. Every quantum field has a fundamental particle, and the particle associated with Higgs field is the Higgs boson. One of the goals of the Large Hadron Collider at CERN was to prove the existence of the elusive Higgs boson once and for all, which it did in 2013 and confirmed in 2017.

History of the universe

The universe was born in a flash nearly 14 billion years ago. Discover what's happened since then…

13.8 BILLION YEARS AGO

0 seconds

The Big Bang

1 The moment the universe was created is called the Big Bang. Nobody knows how or why, but astronomers know the universe is expanding today, so at some point everything must have been closer – a lot closer! One mistake people make is thinking of the Big Bang as an explosion into space, when there was nothing for it to explode into. Everything came into the existence in the Big Bang.

10^{-43} to 10^{-36} seconds

The Grand unification epoch

2 Today we have four fundamental forces: the strong force, the weak force, gravity and the electromagnetic force. But back in the Big Bang, conditions were so unimaginably extreme that three of these four forces – all of them except gravity – were unified as one single force. When physicists talk about finding a Grand Unified Theory, this is what they mean. Gravity had separated from the other forces before this epoch.

10^{-36} and 10^{-32} seconds

Inflation

3 Today, one side of the visible universe looks pretty much like the other. For this to be the case opposite sides of the visible universe must have been in close contact to share their characteristics, but today they are so far apart that light has not had time to travel from one side to another. The answer – possibly – is a period of incredible expansion called inflation, which blew the universe up faster than the speed of light.

3-20 minutes

Creation of atoms

4 After the first three minutes in the universe's already eventful life, it was a raging, chaotic sea of protons, electrons and neutrons. As the universe continued to cool down, the protons and neutrons were able to combine to form simple atomic nuclei, mostly hydrogen, some helium and a smidgen of lithium. This process is called nucleosynthesis. It was still too hot for electrons to join them at this point, though.

380,000 years

Cosmic microwave background radiation

5 It took another 380,000 years for temperatures in the universe to drop below about 3,000 degrees Celsius (5,432 degrees Fahrenheit), which is cool enough for electrons to attach themselves to atomic nuclei. Until this time photons of light were continually absorbed or scattered by the fog of free electrons, so light could never travel far. When the nuclei soaked up the electrons, light suddenly found it could travel unhindered. This is the same light we see today, stretched by the expansion of the universe, as the so-called cosmic microwave background radiation.

200 million years

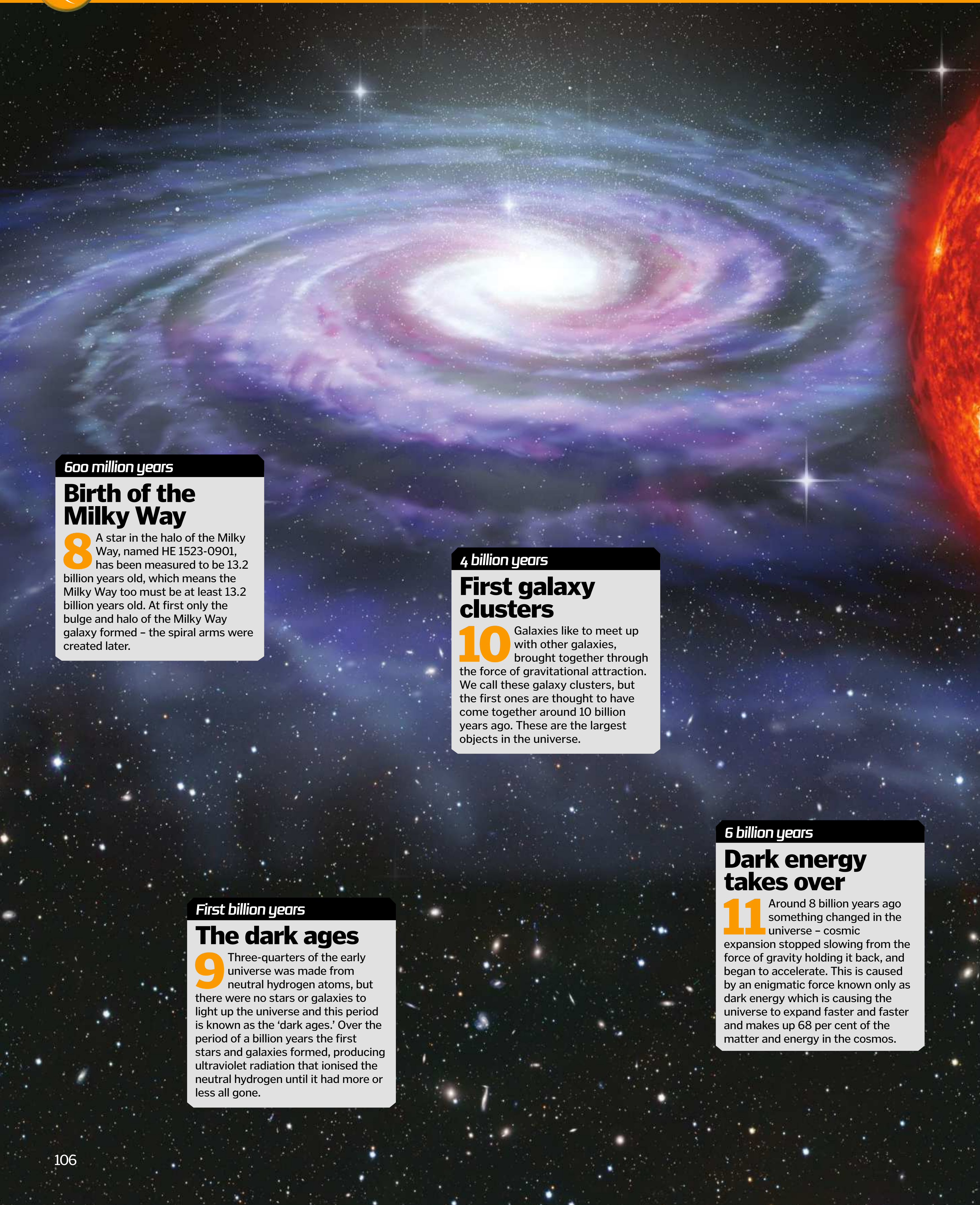
The first stars

6 The first stars were enormous, possibly as much as a thousand times more massive than the Sun, and they were vital in the history of the universe in heating and ionising the hydrogen gas around them. Inside these stars, new elements were created, before being released into the universe to be recycled into new stars and – eventually – planets. The first stars exploded as supernovas.

500 million years

The first galaxies

7 When the first stars exploded, they left behind black holes, which merged and grew larger. Around these black holes more and more gas began to gather and a system of stars would form. These were the first galaxies, just a few hundred light years across but densely packed with star formation. These proto-galaxies would then merge with each other to build into the larger galaxies we see today.



600 million years

Birth of the Milky Way

8 A star in the halo of the Milky Way, named HE 1523-0901, has been measured to be 13.2 billion years old, which means the Milky Way too must be at least 13.2 billion years old. At first only the bulge and halo of the Milky Way galaxy formed – the spiral arms were created later.

First billion years

The dark ages

9 Three-quarters of the early universe was made from neutral hydrogen atoms, but there were no stars or galaxies to light up the universe and this period is known as the 'dark ages.' Over the period of a billion years the first stars and galaxies formed, producing ultraviolet radiation that ionised the neutral hydrogen until it had more or less all gone.

4 billion years

First galaxy clusters

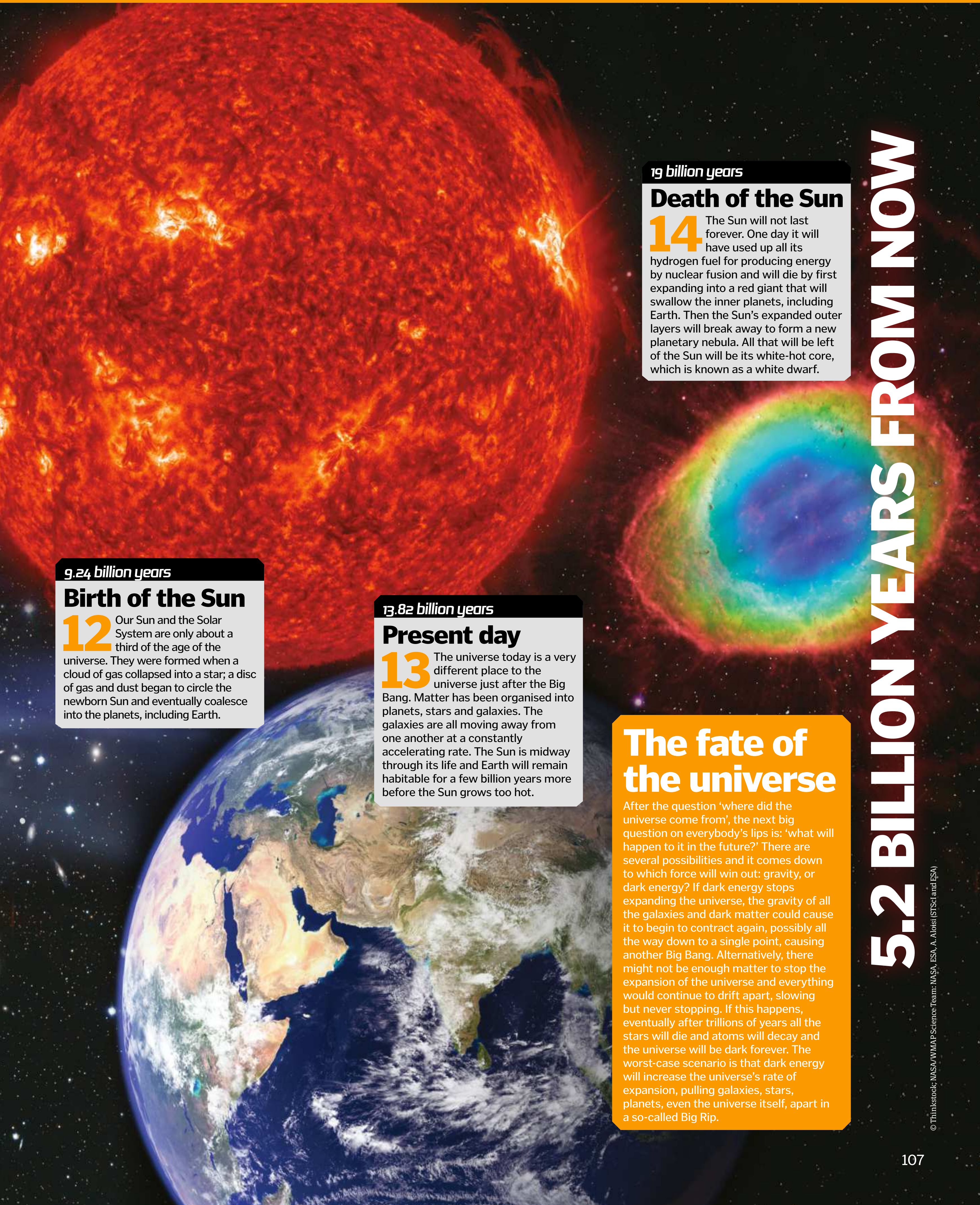
10 Galaxies like to meet up with other galaxies, brought together through the force of gravitational attraction. We call these galaxy clusters, but the first ones are thought to have come together around 10 billion years ago. These are the largest objects in the universe.

6 billion years

Dark energy takes over

11 Around 8 billion years ago something changed in the universe – cosmic expansion stopped slowing from the force of gravity holding it back, and began to accelerate. This is caused by an enigmatic force known only as dark energy which is causing the universe to expand faster and faster and makes up 68 per cent of the matter and energy in the cosmos.

DID YOU KNOW? *The visible universe isn't everything – there is a lot more, but it's so far away that its light has not reached us yet*



9.24 billion years

Birth of the Sun

12 Our Sun and the Solar System are only about a third of the age of the universe. They were formed when a cloud of gas collapsed into a star; a disc of gas and dust began to circle the newborn Sun and eventually coalesce into the planets, including Earth.

13.82 billion years

Present day

13 The universe today is a very different place to the universe just after the Big Bang. Matter has been organised into planets, stars and galaxies. The galaxies are all moving away from one another at a constantly accelerating rate. The Sun is midway through its life and Earth will remain habitable for a few billion years more before the Sun grows too hot.

19 billion years

Death of the Sun

14 The Sun will not last forever. One day it will have used up all its hydrogen fuel for producing energy by nuclear fusion and will die by first expanding into a red giant that will swallow the inner planets, including Earth. Then the Sun's expanded outer layers will break away to form a new planetary nebula. All that will be left of the Sun will be its white-hot core, which is known as a white dwarf.

5.2 BILLION YEARS FROM NOW

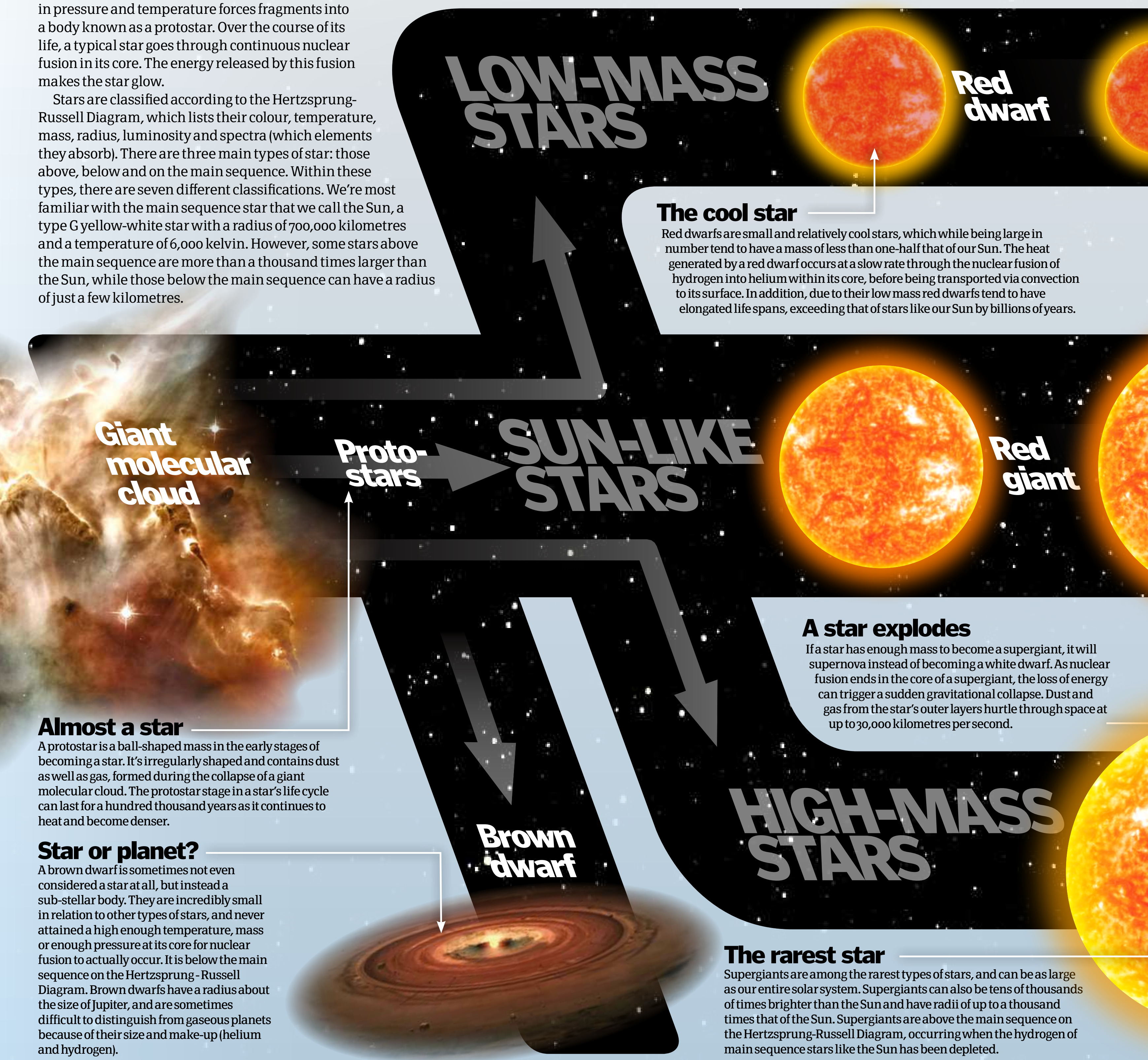
The fate of the universe

After the question 'where did the universe come from', the next big question on everybody's lips is: 'what will happen to it in the future?' There are several possibilities and it comes down to which force will win out: gravity, or dark energy? If dark energy stops expanding the universe, the gravity of all the galaxies and dark matter could cause it to begin to contract again, possibly all the way down to a single point, causing another Big Bang. Alternatively, there might not be enough matter to stop the expansion of the universe and everything would continue to drift apart, slowing but never stopping. If this happens, eventually after trillions of years all the stars will die and atoms will decay and the universe will be dark forever. The worst-case scenario is that dark energy will increase the universe's rate of expansion, pulling galaxies, stars, planets, even the universe itself, apart in a so-called Big Rip.

A star is born

There may be as many as 10 billion trillion stars in the 100 billion galaxies throughout the universe, but "only" about 100 billion in our galaxy, the Milky Way. Most stars comprise plasma, helium and hydrogen. They form when giant molecular clouds (GMCs), also known as star nurseries, experience a gravitational collapse. This increase in pressure and temperature forces fragments into a body known as a protostar. Over the course of its life, a typical star goes through continuous nuclear fusion in its core. The energy released by this fusion makes the star glow.

Stars are classified according to the Hertzsprung-Russell Diagram, which lists their colour, temperature, mass, radius, luminosity and spectra (which elements they absorb). There are three main types of star: those above, below and on the main sequence. Within these types, there are seven different classifications. We're most familiar with the main sequence star that we call the Sun, a type G yellow-white star with a radius of 700,000 kilometres and a temperature of 6,000 kelvin. However, some stars above the main sequence are more than a thousand times larger than the Sun, while those below the main sequence can have a radius of just a few kilometres.



The cool star

Red dwarfs are small and relatively cool stars, which while being large in number tend to have a mass of less than one-half that of our Sun. The heat generated by a red dwarf occurs at a slow rate through the nuclear fusion of hydrogen into helium within its core, before being transported via convection to its surface. In addition, due to their low mass red dwarfs tend to have elongated life spans, exceeding that of stars like our Sun by billions of years.

A star explodes

If a star has enough mass to become a supergiant, it will supernova instead of becoming a white dwarf. As nuclear fusion ends in the core of a supergiant, the loss of energy can trigger a sudden gravitational collapse. Dust and gas from the star's outer layers hurtle through space at up to 30,000 kilometres per second.

Almost a star

A protostar is a ball-shaped mass in the early stages of becoming a star. It's irregularly shaped and contains dust as well as gas, formed during the collapse of a giant molecular cloud. The protostar stage in a star's life cycle can last for a hundred thousand years as it continues to heat and become denser.

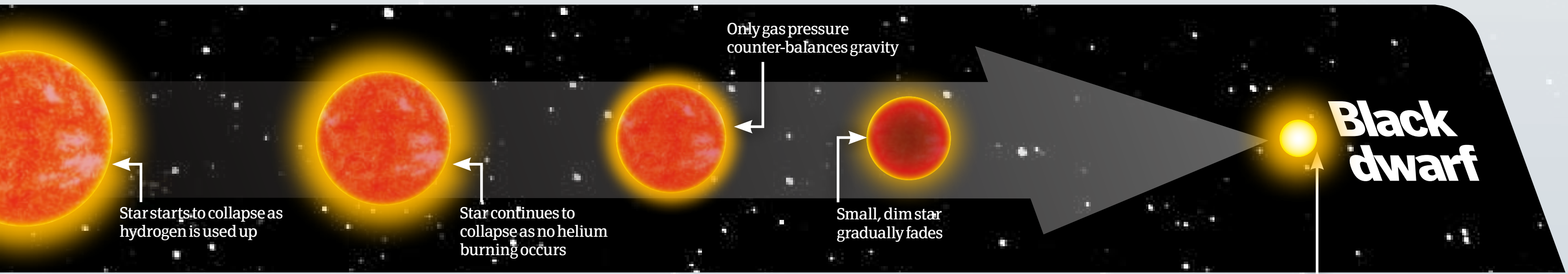
Star or planet?

A brown dwarf is sometimes not even considered a star at all, but instead a sub-stellar body. They are incredibly small in relation to other types of stars, and never attained a high enough temperature, mass or enough pressure at its core for nuclear fusion to actually occur. It is below the main sequence on the Hertzsprung - Russell Diagram. Brown dwarfs have a radius about the size of Jupiter, and are sometimes difficult to distinguish from gaseous planets because of their size and make-up (helium and hydrogen).

The rarest star

Supergiants are among the rarest types of stars, and can be as large as our entire solar system. Supergiants can also be tens of thousands of times brighter than the Sun and have radii of up to a thousand times that of the Sun. Supergiants are above the main sequence on the Hertzsprung-Russell Diagram, occurring when the hydrogen of main sequence stars like the Sun has been depleted.

Compared to other stars, the Sun is in the middle of the pack when it comes to size and temperature



Catch a dying star

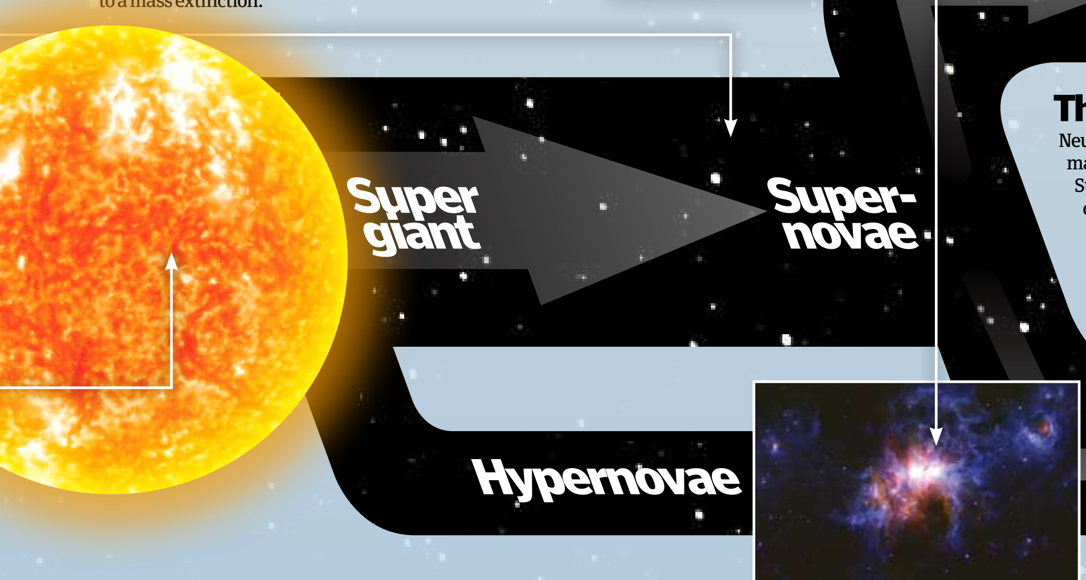
White dwarfs are considered the final phase in a star's life cycle unless it attained enough mass to supernova (and more than 95 percent of stars don't). The cores of white dwarfs typically comprise carbon and oxygen, left over after the gas is used up during nuclear fusion and occurring after a main sequence star has gone through its giant phase. A white dwarf is small, with a volume comparable to that of Earth's, but incredibly dense, with a mass about that of the Sun's. With no energy left, a white dwarf is dim and cool in comparison to larger types of stars.

The stellar remnant

Black dwarfs are the hypothetical next stage of star degeneration after the white dwarf stage, when they become sufficiently cool to no longer emit any heat or light. Because the time required for a white dwarf to reach this state is postulated to be longer than the current age of the universe, none are expected to exist yet. If one were to exist it would be, by its own definition, difficult to locate and image due to the lack of emitted radiation.

Beyond the supernova

A hypernova is a supernova taken to an even larger degree. Supergiant stars with masses that are more than 100 times that of the Sun are thought to have these massive explosions. If a supergiant were close to Earth and exploded into a hypernova, the resulting radiation could lead to a mass extinction.



The neutron dance

Neutron stars are a potential next stage in the life cycle of a star. If the mass that remains after a supernova is up to three times that of the Sun, it becomes a neutron star. This means that the star only consists of neutrons, particles that don't carry an electrical charge.

The absence of light

Stellar black holes are thought to be the end of the life cycle for supergiant stars with masses more than three times that of our Sun. After supernova, some of these stars leave remnants so heavy that they continue to remain gravitationally unstable.

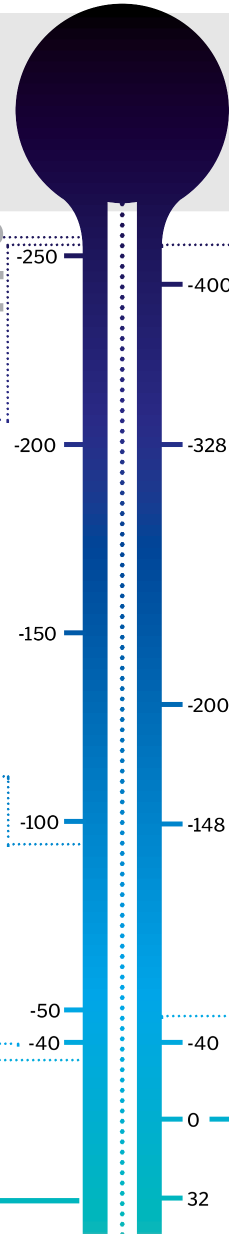
Extreme cosmic temperatures

What are the hottest and coldest temperatures in space, and where can we find them?

Absolute zero

-273.15°C (-459.67°F)

The lowest temperature possible, zero degrees Kelvin.



Elements

-272.2°C/-457.96°F

Lowest freezing point
Helium will remain liquid right down to near absolute zero.

-40°C/-40°F

Equilibrium
The point at which both the Celsius and Fahrenheit scales have the same value.

-38.83°C/-37.89°F

Mercury freezes
Your thermometer will be useless in the depths of an Antarctic winter.

Space tech

Earth

450 picokelvin

Coldest recorded temperature
A team of scientists from MIT cooled sodium gas to a fraction above absolute zero.

-93.2°C/-135.8°F

Coldest place on Earth
This was measured in eastern Antarctica by a NASA satellite, so is not an official Guinness world record.

Solar System

-240°C/-400°F

Lunar craters
The Moon is cold enough anyway, but there are craters on its surface in permanent shadow that never rise above this temperature.

Milky Way

-272°C/-458°F

Deep space refrigerator
The Boomerang nebula 5,000 light years from Earth, is the coldest natural place in space.

-48°C/-54°F

Coldest brown dwarf star
Sub-stellar objects can achieve surprisingly low temperatures, including this record-breaking neighbour of ours that is just 7.2 light years away.

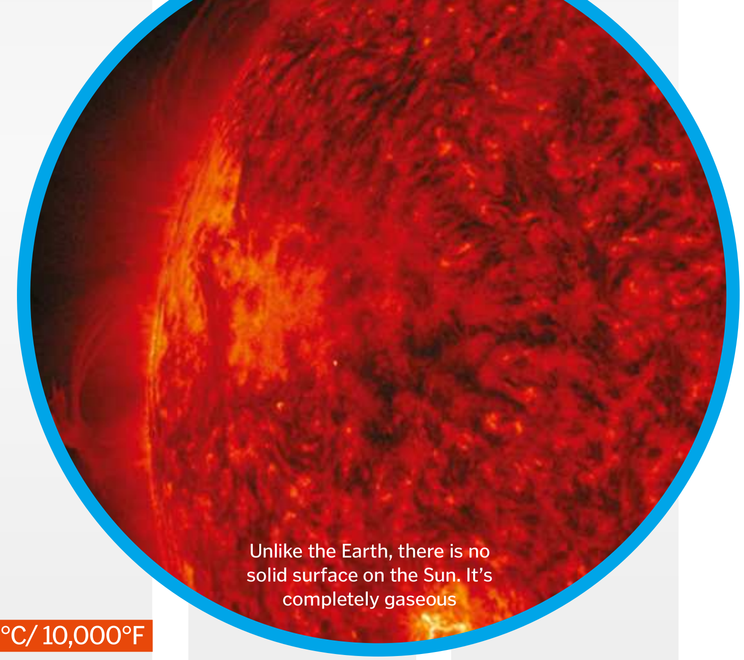
Universe

Pluto's icy heart

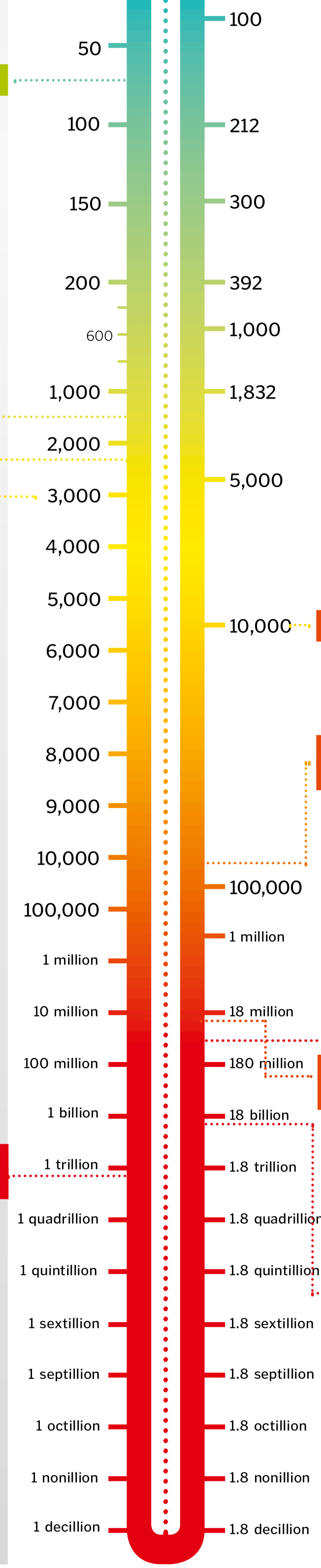
From a distance of 450,000 kilometres (280,000 miles) away, New Horizons' Long Range Reconnaissance Imager (LORRI) took four photos to create this composite colour image of Pluto, revealing some curious details. The heart-shaped Tombaugh region (named after the astronomer who discovered Pluto in 1930) is split into two lobes in this image, and it's thought that temperatures as low as -223 degrees Celsius (-369 degrees Fahrenheit) cause nitrogen to precipitate as snow and flow from one side of the region to the next in massive glaciers. The team at New Horizons mission control also think that this vast area acts as a kind of reservoir that feeds both its geological and atmospheric activity.

0°

0°



Unlike the Earth, there is no solid surface on the Sun. It's completely gaseous



70.7°C/159.3°F

Hottest place on Earth

The Lut desert in Iran achieved this record in 2005. It was measured by satellite.

2,200°C/3,992°F

Atmospheric re-entry

The heat shield on NASA's new Orion capsule will protect its crew from blistering temperatures when re-entering the Earth's atmosphere.

1,538°C/2,800°F

Iron melts

Under intense pressure, such as at the Sun's core, iron will remain in a liquid state even at extreme temperatures.

3,093°C/5,600°F

Rocket boosters

The temperature within the booster of NASA's Space Launch System – the most powerful rocket booster ever built – during tests.

Heat of the Big Bang

In the first few moments of its formation, the universe was pretty toasty to say the least, with a temperature in excess of four trillion degrees Celsius (7.2 trillion degrees Fahrenheit). The universe was so hot and dense that protons and neutrons could not exist, but their constituent elementary particles formed a quark-gluon plasma. This so-called "quark soup" was 250,000 times hotter than the Sun's core, but it cooled as the universe expanded. At 100 seconds after the Big Bang, the universe was at one billion degrees Celsius (1.8 billion degrees Fahrenheit), but it took 380,000 years before the first hydrogen and helium atoms could form.

5.5 trillion°C/ 9.9 trillion°F

Hottest recorded temperature

This gong goes not to a star or even a supernova, but was briefly generated by the man-made particle accelerator, the Large Hadron Collider.

5,500°C/ 10,000°F

Surface of the Sun

Hot enough to boil iron.

24,000°C/ 43,232°F

Core of Jupiter

The immense pressure at Jupiter's core from this massive planet, makes it a massive five times hotter than the Sun's surface.

15,000,000°C/ 27,000,000°F

Core of the Sun

Not surprisingly, this is the hottest place in the Solar System, where each of the fusion reactions take place.

55,000,000°C/ 99,000,032°F

Supernova gas

The energy of a supernova can heat the gas surrounding it to blistering temperatures.

100 billion°C/ 180 billion°F

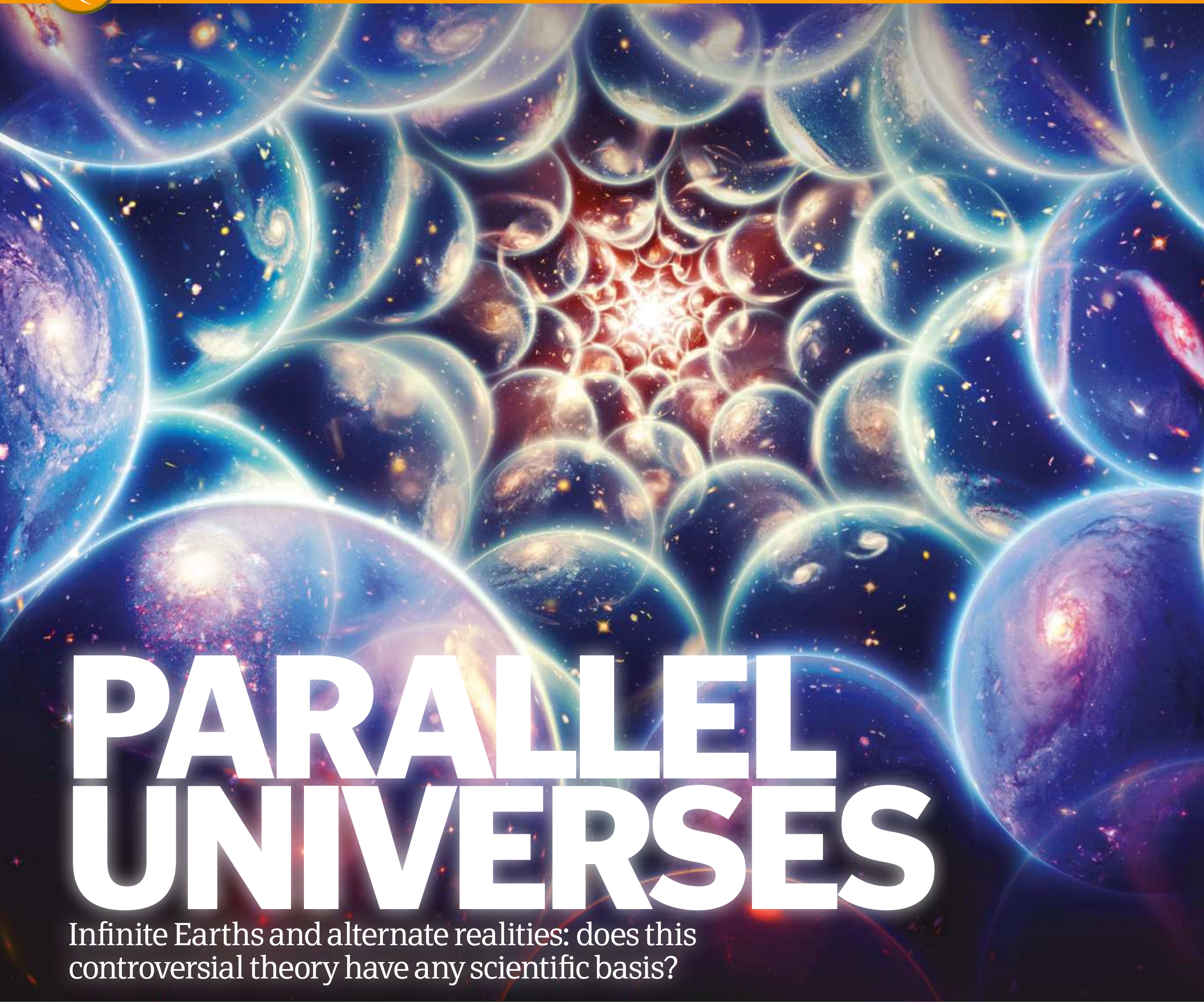
Core of a newly-formed neutron star

Massive stars that collapse sometimes leave behind these incredibly hot and dense remnants.

Planck temperature

142,000,000,000,000,000,000,000,000,000,000°C (255,000,000,000,000,000,000,000,000,000,000°F)

The hottest (theoretical) temperature of matter achievable.



PARALLEL UNIVERSES

Infinite Earths and alternate realities: does this controversial theory have any scientific basis?

It's an understatement to say that the multiverse theory is one of the most controversial theories in science. In fact, merely putting this in the Space section of the magazine, and not a newly created Theology section, would ruffle a few astrophysicists' feathers. But why is this the case, and is there any basis for suggesting we live in a multiverse?

The origins of the multiverse theory are a grey area. Some, like David Deutsch in his book *The Beginning of Infinity*, point to Erwin Schrödinger and his famous equation. This broadly introduced the idea of quantum mechanics, in which a particle can be in two states at once, in the first half of the 20th century. It would be many years until the broader implications of the theory were given serious thought, though.

You're probably more familiar with the multiverse theory in different terms – parallel universes – so let's begin there. At its core, the multiverse theory suggests that our universe is not alone, but perhaps one of many in some form or another. Just as we discovered Earth was one of many planets, and that the Milky Way was one of many galaxies, some scientists think the same could be said of the universe.

As of yet, we have no direct evidence for multiverses (and even that prospect is contentious, which we'll come on to later). But our best indirect evidence for its existence is a peculiar one. It stems from how exact certain mathematical constants in the universe are. The cosmological constant, for example, is a value for the energy density of the vacuum of space. Its existence explains how the universe is expanding at an ever-increasing speed, something first discovered in 1998.

But the cosmological constant is 120 orders of magnitude smaller (that is, ten to the power of minus 120) than theory predicts it should be. Thus, even a small change in its value would have rendered our universe a mess of nothingness after the Big Bang. So, too, for the values of dark energy. How were these mathematical constants so finely created?

"If [dark energy] had been any bigger, there would have been enough repulsion from it to overwhelm the gravity that drew the galaxies together, drew the stars together, and drew Earth together," Stanford physicist Leonard Susskind told *Discover Magazine* in 2008. "It's one of the

greatest mysteries in physics. All we know is that if it were much bigger we wouldn't be here to ask about it."

The multiverse theory has an answer, though. It suggests that in our universe, the cosmological constant is exactly the right value for everything as we know it to exist. But there are an infinite number of other universes, where it is ever so slightly different.

Working on the pretence that this is true, what form would these other universes take? That's the tricky part. There are a large number of theories, from Max Tegmark's four levels of classification (explained later), to M-theory (which encompasses string theory), to cyclic theories, where the universe is in an infinite number of cycles between Big Bangs and Big Crunches.

Tegmark's four levels encompass the broader multiverse theories. The Massachusetts Institute of Technology professor suggested them in 2003, presenting them as a way to classify ideas for the multiverse. "Parallel universes are not a theory, but a prediction of certain theories," he said in his 2014 book *Our Mathematical Universe*. The first level deals with the observable universe, which is the extent to which we can see in the universe. Owing to the finite speed of light, we are only able to see as far as light has been able to travel to us since the Big Bang, 13.8 billion years ago. Due to the expansion of the universe, though, we are able to see light that is now more than 42 billion light years from us, which we call the observable universe. But we cannot see beyond this; what is there, we just don't know.

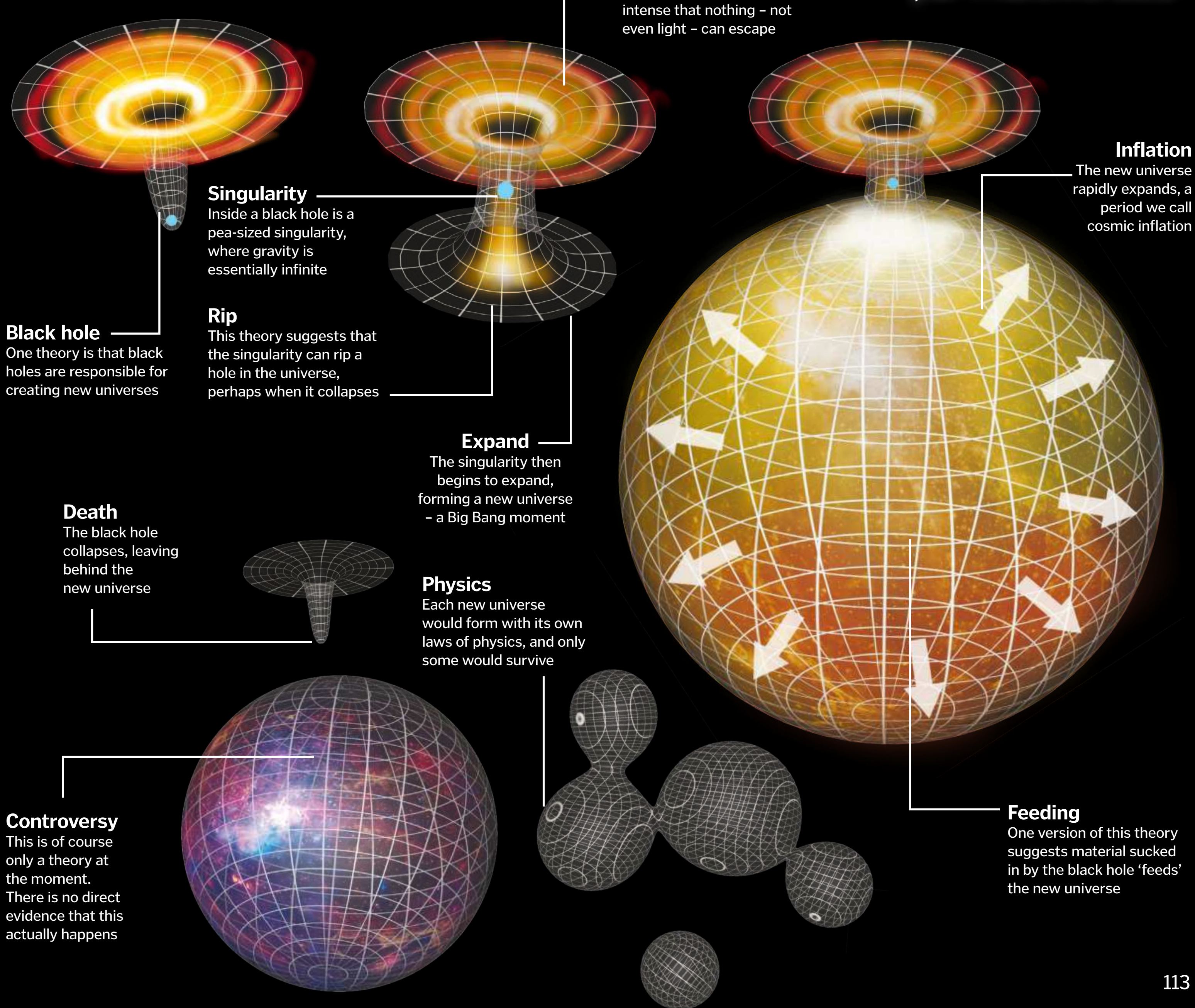
Tegmark's first multiverse level suggests that there is no end. Instead, the universe just keeps going and going, infinitely. If true, this would create an infinite number of instances for everything to occur. So, at some astronomical distance away from us, we would find an Earth exactly the same as ours, and you would find yourself sitting there reading this very article.

The second level is similar to the first, but proposes that while the whole multiverse is expanding, there are regions within it that expand at different rates, forming bubbles of self-confined space – in other words, bubble universes. Our universe would be one bubble, with an untold number of other bubbles beyond, each with their own laws of physics. In 2015, a later, widely discredited theory suggested

Building a multiverse

Are universes born in black holes?

"As of yet, we have no direct evidence for multiverses"



bubble universe had actually 'bumped' into one another, producing a noticeable glow in the far reaches of space.

In the third level, things start to get a little bit strange. Like the first, it suggests that the laws of physics are the same everywhere, but rather than different universes being separated by distance, as in the second level, they are in fact separated by time. The laws of quantum mechanics, as mentioned earlier, allow for a large number of uncertainties and possible futures (for example, whether Schrödinger's famous 'cat in the box' is dead or alive). In this level, all of these possibilities would play out. Every single eventuality would occur, and each time, a new universe would be created along with it. For us as observers, though, we only see one universe – our own.

The fourth and final level, the mathematical multiverse, is fairly difficult to comprehend. It is Tegmark's own theory, presented in *Our Mathematical Universe*. It essentially implies that the universe is composed entirely of mathematics, and we are merely constructs within that. But the book and theory have come under some heavy criticism.

One of the main arguments against the multiverse theory, though, is that it fails one of the very cornerstones of science itself: falsifiability. This is the ultimate test for any scientific theory, namely that it can be proven wrong. For example, if you put forward the theory that every animal on Earth had four legs, someone else could refute that theory by finding an animal with more or less than four.

No multiverse theory is currently falsifiable. We simply don't have the means to disprove some of the claims being made. We will never be able to journey beyond the observable universe, and

Different types of multiverse

"We have no way of jumping to another universe"

LEVEL ONE: An extension

Our views into the universe are limited by the age of the universe. We cannot see further than the time light has had to travel to us, which when you take the expansion of the universe into account, comes to 42 billion light years.

But this multiverse theory suggests that, beyond this distance, the universe continues into infinity. And this would mean that eventually, by chance, everything would start to repeat itself – even Earth itself. It will be impossible to ever know what is beyond our observable universe though, without finding some fanciful way to travel faster than light. Until then, we may never know what is beyond our vision.

LEVEL TWO: The bubble universe

This theory proposes that there are many 'bubble' universes living alongside each other. The key behind the theory is cosmic inflation, which is the period of rapid expansion the universe went through in its first trillionth of a trillionth of a trillionth of a second. This ultimately gave rise to the universe as we know it.

According to this theory, different regions of space expanded at different rates, forming their own 'bubble' regions alongside ours. In theory, there could be an infinite number of these bubble universes alongside ours, with a contentious version suggesting each has its own laws of physics.

thus could never disprove the notion that there are other parallel bubble universes out there, or an infinite universe. As such, many argue that the multiverse theory should not be treated as a theory at all. It should be condemned to the pseudoscience bin.

"The trouble is that no possible astronomical observations can ever see those other universes," said cosmologist George Ellis in an article published in *Scientific American* in 2011. "The arguments are indirect at best. And even if the multiverse exists, it leaves the deep mysteries of nature unexplained."

Of course, falsifiability itself has its detractors. Other more widely accepted theories, such as the existence of dark matter or dark energy, may not be falsifiable. Should we also consign those to the scrapheap? It's fair to say that this is a topic that draws heated debate in the scientific community.

And even aside from falsifiability, we run into a problem. Not only can we not disprove multiverse theories, but we can't currently prove them either. We have no way of jumping to another universe, or even observing one. How are we supposed to sift through the myriad of claims being made when there is no direct evidence available?

The idea of a multiverse is undoubtedly an intriguing one. It has inspired a huge range of science fiction, and has garnered support from some of the most prominent physicists today. "It would not be beyond the realms of possibility that somewhere outside of our own universe lies another different universe," Professor Stephen Hawking said in 2015. But it remains divisive, and will do so for the foreseeable future. For now, it remains a fringe theory in some corners of the scientific world. And perhaps in an issue of *How It Works* in an alternate universe, it is indeed confined to the Theology section.

LEVEL THREE: Many worlds

The many-worlds theory relies on quantum mechanics. The quantum world is odd, in that things such as photons can appear to be in two places, or states, at once. It is only when we observe the photon that its state is decided.

In this theory, though, both states exist. And, in fact, this is happening constantly for everything around us, at all times. Each time there is a 'split', a new universe is created, giving rise to an infinite number of universes. This is probably the closest theory to the idea of 'parallel universes' where one could envision jumping into a nearby universe. It's pretty unlikely that'll ever be possible, though.

LEVEL FOUR: Mathematical universe

This theory is probably the one that is most widely derided. Max Tegmark goes into detail in his doorstop of a book *Our Mathematical Universe*, but in essence, it suggests that our universe, and all other universes, are nothing but mathematical constructs. We are quite simply lumps of mathematics manifested as a consciousness that can perceive this seemingly 'real' world.

It is described by some as the 'ultimate ensemble' and, owing to its nature being everything broken down into mathematics, there cannot be another broader multiverse theory beyond it. As you might have guessed, it's a bit controversial.

Arguments for and against the multiverse

FOR

Cosmic inflation
Our universe grew exponentially in the first moments of its existence, but was this expansion uniform? If not, it suggests different regions of space grew at different rates – and may be isolated from one another.

Mathematical constants
How are the laws of our universe so exact? Some propose that this happened only by chance – we are the one universe out of many that happened to get the numbers right.

The observable universe
What is beyond the edge of the observable space around us? No one knows for sure, and until we do (which could be never), the thought that our universe extends infinitely is an interesting one.

AGAINST

Falsifiability
There is no way for us to ever test theories of the multiverse. We will never see beyond the observable universe, so if there is no way to disprove the theories, should they be given credence?

Occam's razor
Sometimes, the simplest ideas are the best. Some physicists argue that we don't need the multiverse theory at all. It doesn't solve any paradoxes, and only creates new complications.

No evidence
Not only can we not disprove any multiverse theory, we can't prove them either. We currently have no evidence that multiverses exist, and everything we can see suggests there is just one universe – our own.

Hubble has shown us more of the universe than we ever expected

Dark history

The Hubble Space Telescope has successfully mapped a cross-section of dark matter in the universe to a distance of 6.5 billion light years. Astronomers measured the shape of galaxies in images of this cross-section – the huge amount of dark matter acts as a gravitational lens, warping the light from the galaxies. The degree of lensing shows how much dark matter is present. The results showed that dark matter has become clumpier with time, as gravity pulls it and ordinary matter into a giant web across the universe.

THE MYSTERY OF DARK MATTER

Hunting for the invisible mass that makes up 85 per cent of matter in the universe

Out there in the universe, something is going on that we're not able to fully explain. Over three billion light years away from Earth, two great clusters of galaxies are colliding. The stars in both are relatively unaffected in the melee, but clouds of hot, X-ray emitting gas are crashing into one another, stitching the two galaxy clusters into one new one: meet the Bullet Cluster, one of the most energetic events in the cosmos. Yet amid the epic confrontation of the clusters, something mysterious lurks, something for which the only name we have is 'dark matter'.

Within the Bullet Cluster we can see the galaxies. We can see the gas, which actually makes up most of the mass that emits light, more than even the galaxies. But there is a completely invisible component – dark matter – yet its presence is perhaps the most crucial.

Dark matter's name implies that this mysterious substance is dark, but it is more than that – it is invisible, refusing to emit or absorb any forms of light or radiation that could reveal its existence. It passes straight through ordinary matter. We cannot smell, taste, touch or see it. What we do know is that it accounts for 27 per cent of all the mass and energy within the universe (normal matter is only five per cent and dark energy, the mysterious force accelerating the expansion of the universe, makes up the remaining 68 per cent) and it's likely to be made of some form of undiscovered subatomic particle.

"Little is known about it and all that the numerous searches for dark matter particles have done is rule out various hypotheses, but there have never been any 'positive' results", says astrophysicist Maxim Markevitch, who has carefully studied the Bullet Cluster for the effects of dark matter using NASA's Chandra X-ray Observatory.

However, there is one way in which it grabs our attention, which is through the force of gravity. One of the effects of this is clearly played out in the Bullet Cluster. It is this that allows astronomers to work out where the dark matter in the Bullet Cluster is located, even though we cannot even see it. Albert Einstein's General Theory of Relativity described how mass can bend space. Some

people like to use the analogy of a cannonball on a sheet of rubber - the cannonball causes the sheet to sag. If you imagine the ball is an object like a galaxy or a star and the rubber sheet as space, you can see how mass bends space. However, light prefers to take straight paths through the universe, so what happens when it arrives at a region of space that has been warped in this manner? The light will follow the path of curved space, bending its trajectory. In this way a massive object in space can act like a lens, bending and magnifying light. This effect was predicted by Einstein nearly 100 years ago and we call these gravitational lenses.

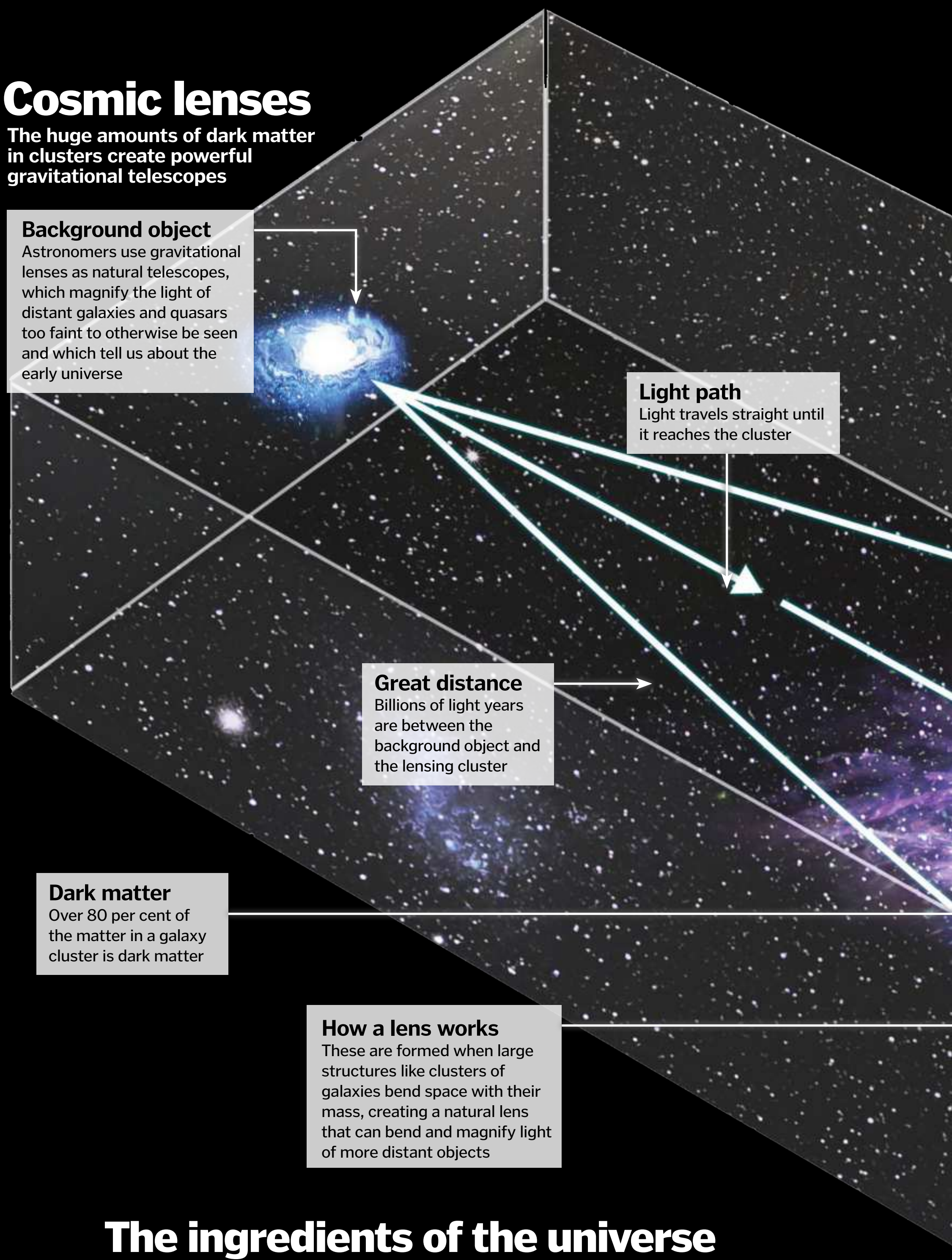
Because galaxy clusters are so huge, they create formidable gravitational lenses. They can magnify the light of even more distant galaxies, but it is not a clear image, rather distorted arcs or smudges of light and occasionally a complete ring. We can see gravitational lensing by the Bullet Cluster, magnifying the light of distant galaxies. But when scientists analysed the gravitational lens, they found something stunning – the lensing effect was too strong to be accounted for by the mass of only the galaxies and the gas. There must be some other type of mass there, hidden. This is dark matter. From the pattern of the lensing, it is possible to work out where the dark matter in the cluster is, which has lead to another remarkable discovery. As the clusters collided, the galaxies and the gas have begun to merge, but the dark matter surrounding each cluster has slid silently through, not interacting with anything at all.

The Bullet Cluster was not the first time we saw the effects of dark matter. That discovery goes all the way back to 1933 when famous astronomer Fritz Zwicky at the California Institute of Technology (Caltech) noticed that galaxies orbiting around the edge of galaxy clusters were moving faster than they should.

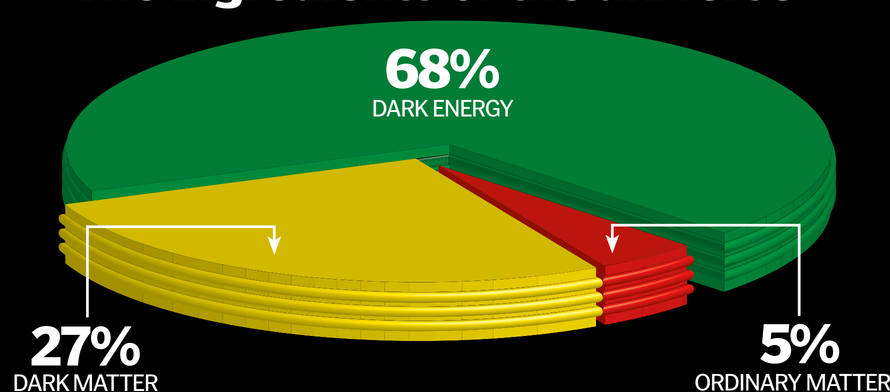
Why should they be moving at a particular speed? In the 17th Century, Johannes Kepler devised his laws of orbital motion, the third one being that "the square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit." In other words, the farther from the Sun, and therefore the centre of mass of the Solar System, the slower a planet orbits. This should also be the case for galaxies orbiting galaxy clusters, but Zwicky found that galaxies on the edges of clusters were orbiting just as fast as those closer in. This implied there must be some unseen mass in the cluster helping things along with its gravity. He called this dark matter, but his idea was generally ignored. It was only in the 1970s when astronomer Vera Rubin of the Carnegie Institution for Science noticed the

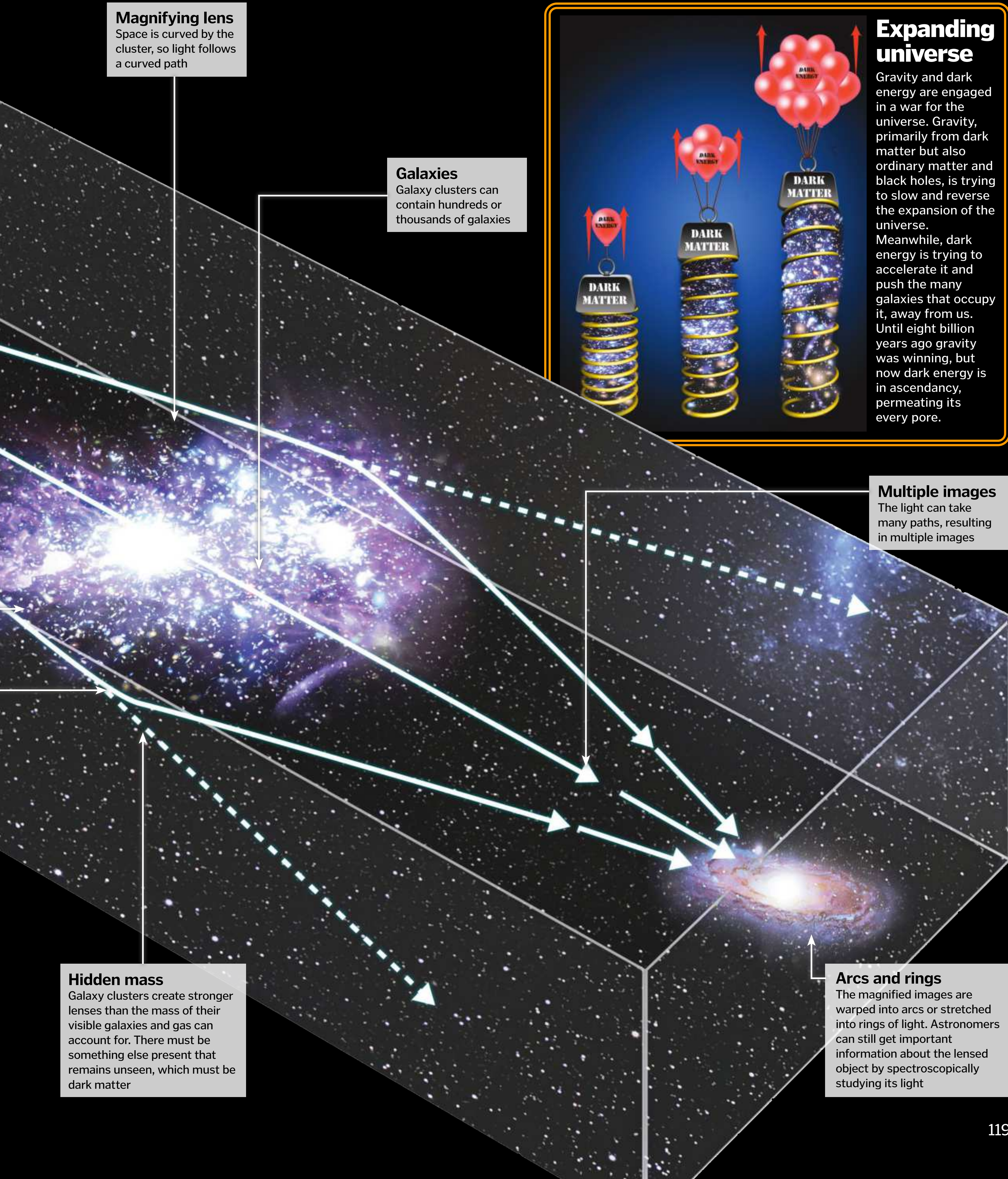
Cosmic lenses

The huge amounts of dark matter in clusters create powerful gravitational telescopes



The ingredients of the universe



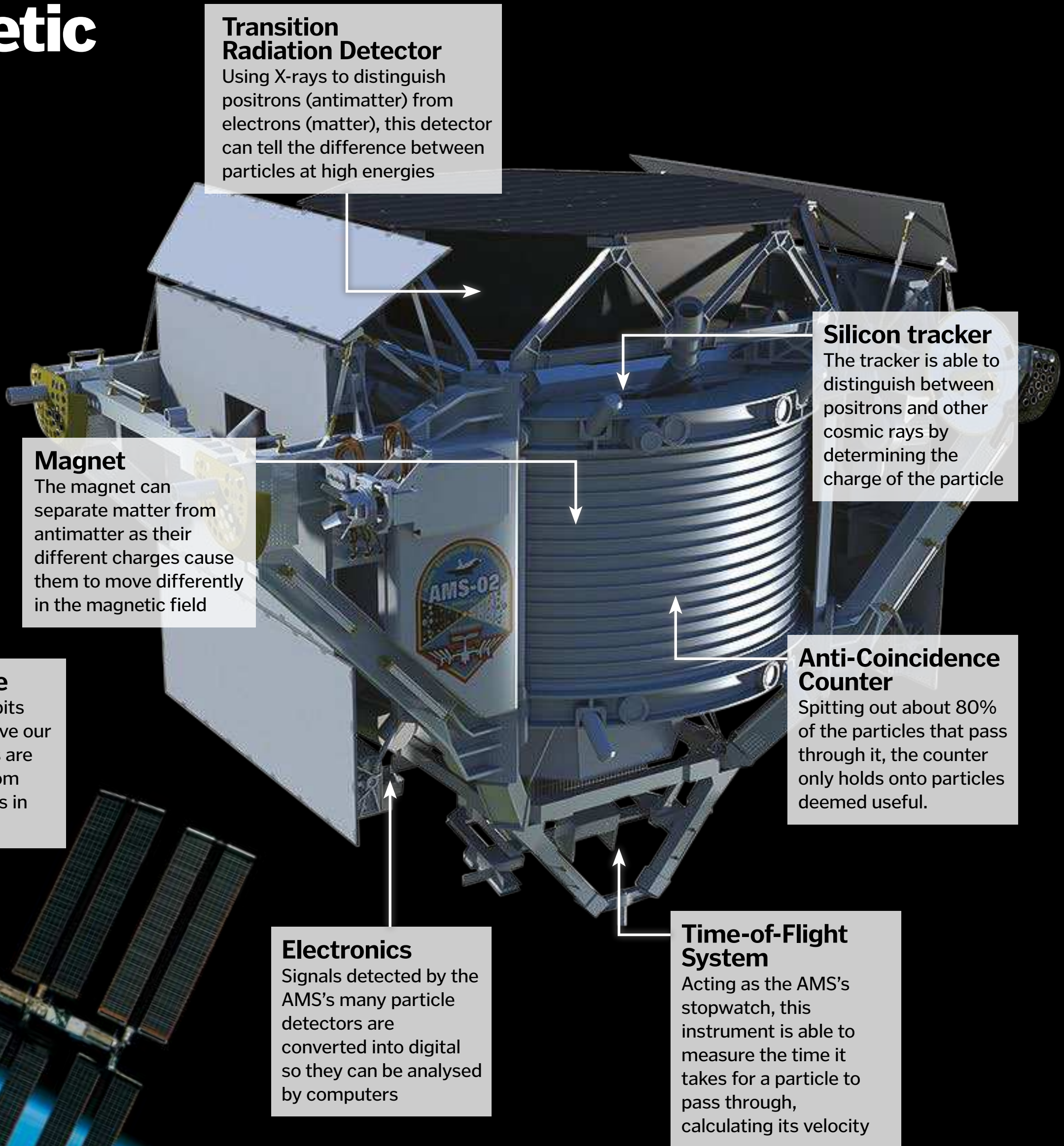


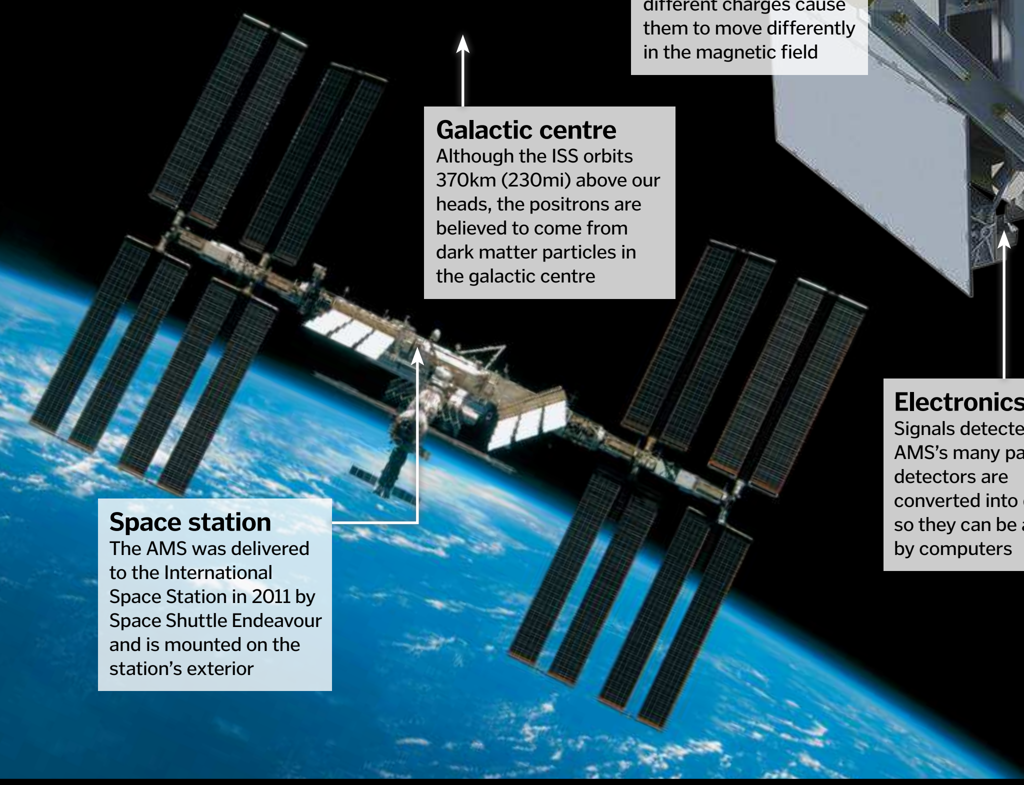
Expanding universe

Gravity and dark energy are engaged in a war for the universe. Gravity, primarily from dark matter but also ordinary matter and black holes, is trying to slow and reverse the expansion of the universe. Meanwhile, dark energy is trying to accelerate it and push the many galaxies that occupy it, away from us. Until eight billion years ago gravity was winning, but now dark energy is in ascendancy, permeating its every pore.

The Alpha Magnetic Spectrometer

Scientists are attempting to detect evidence for dark matter in an experiment called the Alpha Magnetic Spectrometer (AMS) on board the International Space Station. It is designed to detect charged particles called positrons, a type of antimatter, which are thought to be emitted at certain energies when two dark matter particles collide. In 2013, scientists studying the data from AMS revealed it had detected more than 400,000 positrons at those energies, strongly hinting they were from dark matter, although there was not enough information to be certain.





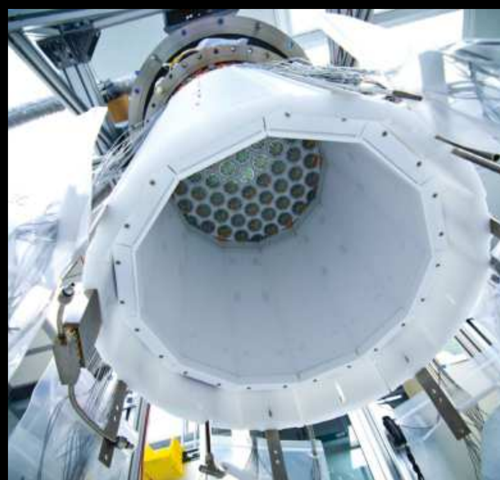
same problem with the orbits of stars and gas near the edges of galaxies. This time the problem was noticed and today dark matter is one of the biggest puzzles of cosmology. Dark matter now forms an integral part of our models of how galaxies grow – we envisage galaxies in halos of dark matter, which is spread across the universe in a great cosmic web, pulling matter toward it and making galaxies and clusters expand.

The Bullet Cluster might hold the best evidence for dark matter, but astronomers and particle physicists seeking to shed light on this substance are building new experiments to try to catch dark matter so that we can finally find out what it is. Although evidence from space suggests that dark matter does not interact with ordinary matter on large scales, physicists suspect that on the scale of individual particles, dark matter sometimes does interact. There must be trillions of these particles passing through us at any given moment, but the interactions are so rare that scientists may have to wait years in order to observe one. Physicists describe these particles as WIMPs, an abbreviation that stands for Weakly Interacting Massive Particles.

In order to trap a dark matter particle in the act, most experiments take place far underground, away from any cosmic ray radiation on the surface that could potentially interfere with and contaminate the results. Experiments such as the Cryogenic Dark Matter Search, located in a mine in Minnesota in the United States, have freezing cold detectors, cooled to fractions of a degree above absolute zero, in order to help them search for the heat produced when a

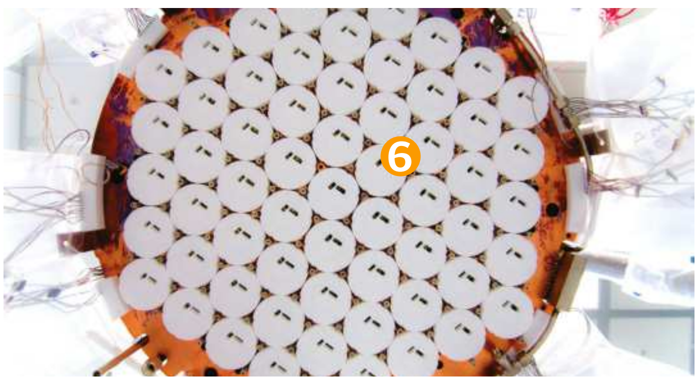
Dark matter is for WIMPs

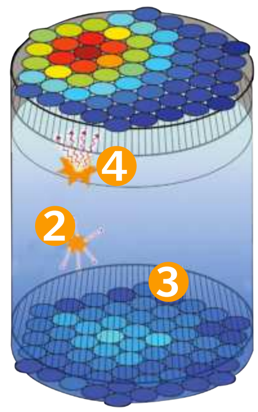
The Large Underground Xenon (LUX) experiment is buried deep beneath South Dakota, now home to the Sanford Underground Laboratory. It consists of a large tank filled with 370 kilograms (816 pounds) of liquid xenon and works on the assumption that dark matter is made of Weakly Interacting Massive Particles, or WIMPs. Occasionally a WIMP should interact with a xenon atom, emitting electrons and ultraviolet light. LUX has been working since 2012 and so far has found no evidence for WIMPs, but this has allowed scientists to constrain their models to narrow the search.



Going underground

The Large Underground Xenon experiment is searching for dark matter in South Dakota





1 Liquid xenon Some theories on dark matter suggest it could occasionally interact with atoms such as xenon.

2 Interaction During the interaction, the xenon atoms recoil and an electron and a UV photon are emitted.

3 Ultraviolet At a wavelength of 175nm, the UV photons are detected by sets of photomultiplier tube.

4 Electrons The electrons drift to the top of the tank where they are electrically stimulated to emit visible light.

5 Tank The experiment is shielded inside an 8x6m (26.2x19.7ft) water tank that keeps out external radiation.

6 Light sensors Two sets of photomultiplier tubes, 122 in all, are arranged at the top and bottom of the experiment.

7 Cryostat The experiment has to be kept cold for xenon to remain liquid, cooling LUX to -120°C (-184°F).

WIMP collides with an atom of a substance such as germanium. Another experiment, the Large Underground Xenon (LUX) dark matter detector, is located 1.6 kilometres (one mile) under the Black Hills of South Dakota, USA. It contains tanks of liquid xenon for WIMPS to interact with, the interaction producing signature radiation that can then be detected.

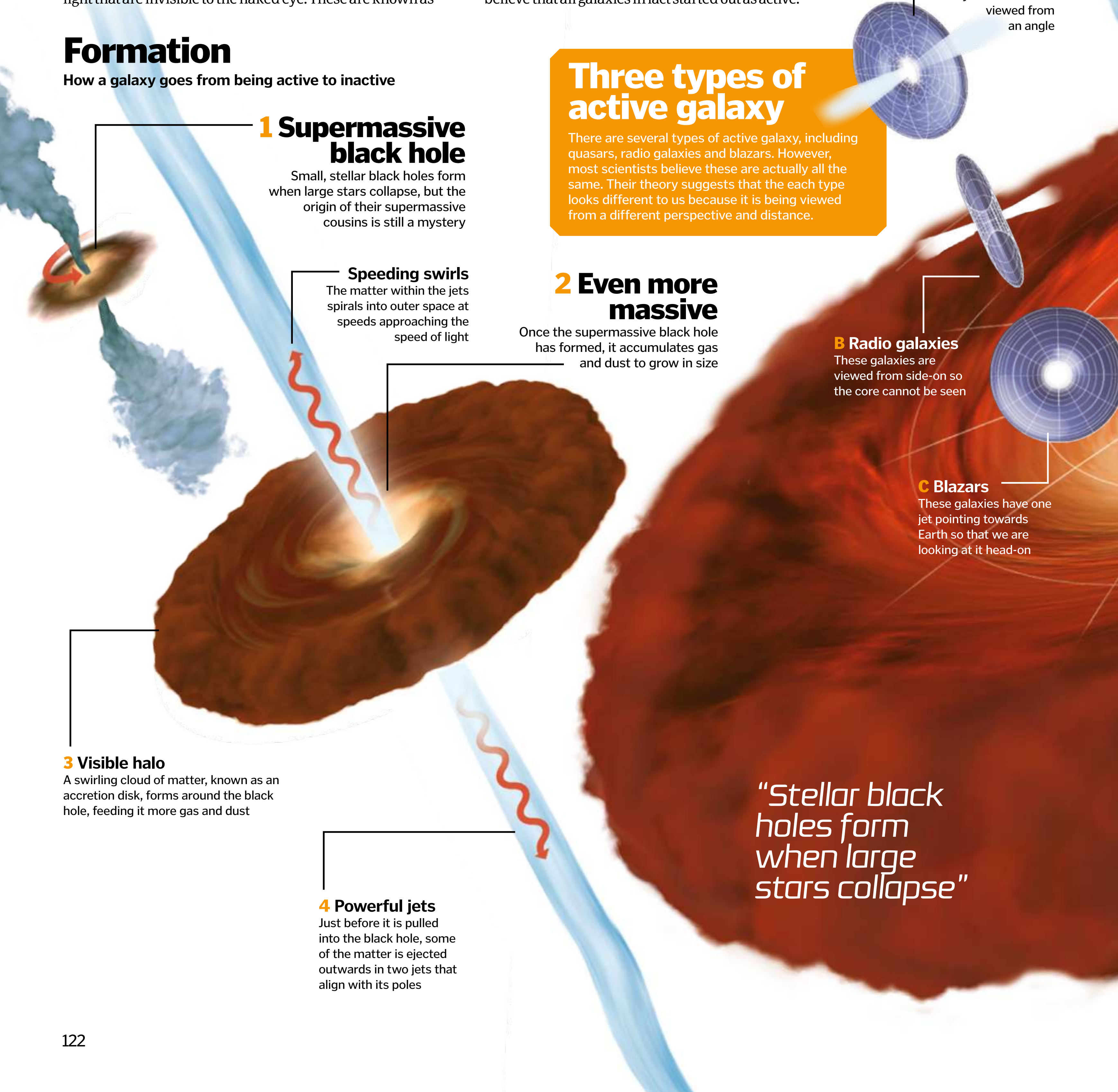
The hunt for dark matter also takes place in space, however. On rare occasions dark matter particles could collide and annihilate each other, releasing an antimatter particle known as a positron (the anti-particle to the negatively charged electron), but because there is so much dark matter in space, particularly in dense clusters close to the centre of the galaxy, there should in theory be a steady stream of positrons being produced. Now an experiment on the International Space Station, the Alpha Magnetic Spectrometer, may have detected some of these positrons.

Some astronomers think we shouldn't be searching for dark matter at all, as they don't believe it even exists. Concerned that dark matter theory adds more complexity to the universe than is necessary, they argue that the gravitational effects we infer as being down to dark matter suggest that we simply need to tweak the laws of gravity instead. As a result, dark matter now has a theoretical rival called Modified Newtonian Dynamics, or MOND. Will the theory of dark matter be usurped or vindicated? As time goes on, the chances of experiments detecting dark matter will increase, so the answers for which we've been searching may soon come into the light.

Active galaxies

The powerful galaxies that swallow their surroundings

A galaxy is a large system of stars, gas, dust and dark matter bound together by gravity. Most normal galaxies emit light from their stars, but a small number give off an enormous amount of energy from their centre in wavelengths of light that are invisible to the naked eye. These are known as active galaxies and their energy emission is driven by supermassive black holes at their core. Such black holes actually lie at the centre of every large galaxy, including the Milky Way, but most are now inactive. This has led many scientists to believe that all galaxies in fact started out as active.



Formation

How a galaxy goes from being active to inactive

1 Supermassive black hole

Small, stellar black holes form when large stars collapse, but the origin of their supermassive cousins is still a mystery

Speeding swirls

The matter within the jets spirals into outer space at speeds approaching the speed of light

2 Even more massive

Once the supermassive black hole has formed, it accumulates gas and dust to grow in size

3 Visible halo

A swirling cloud of matter, known as an accretion disk, forms around the black hole, feeding it more gas and dust

4 Powerful jets

Just before it is pulled into the black hole, some of the matter is ejected outwards in two jets that align with its poles

Three types of active galaxy

There are several types of active galaxy, including quasars, radio galaxies and blazars. However, most scientists believe these are actually all the same. Their theory suggests that the each type looks different to us because it is being viewed from a different perspective and distance.

A Quasars

These are located billions of light years away from Earth and viewed from an angle

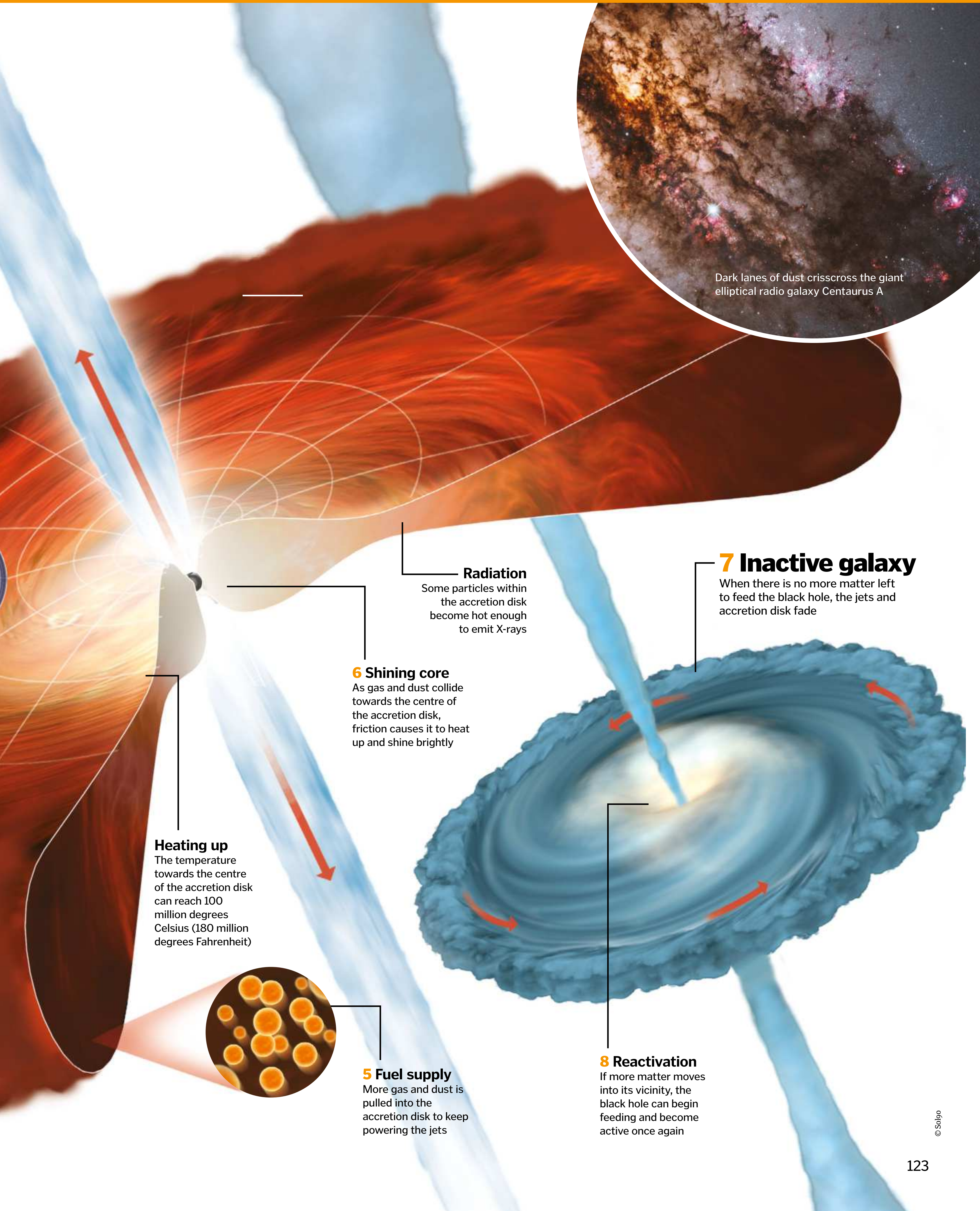
B Radio galaxies

These galaxies are viewed from side-on so the core cannot be seen

C Blazars

These galaxies have one jet pointing towards Earth so that we are looking at it head-on

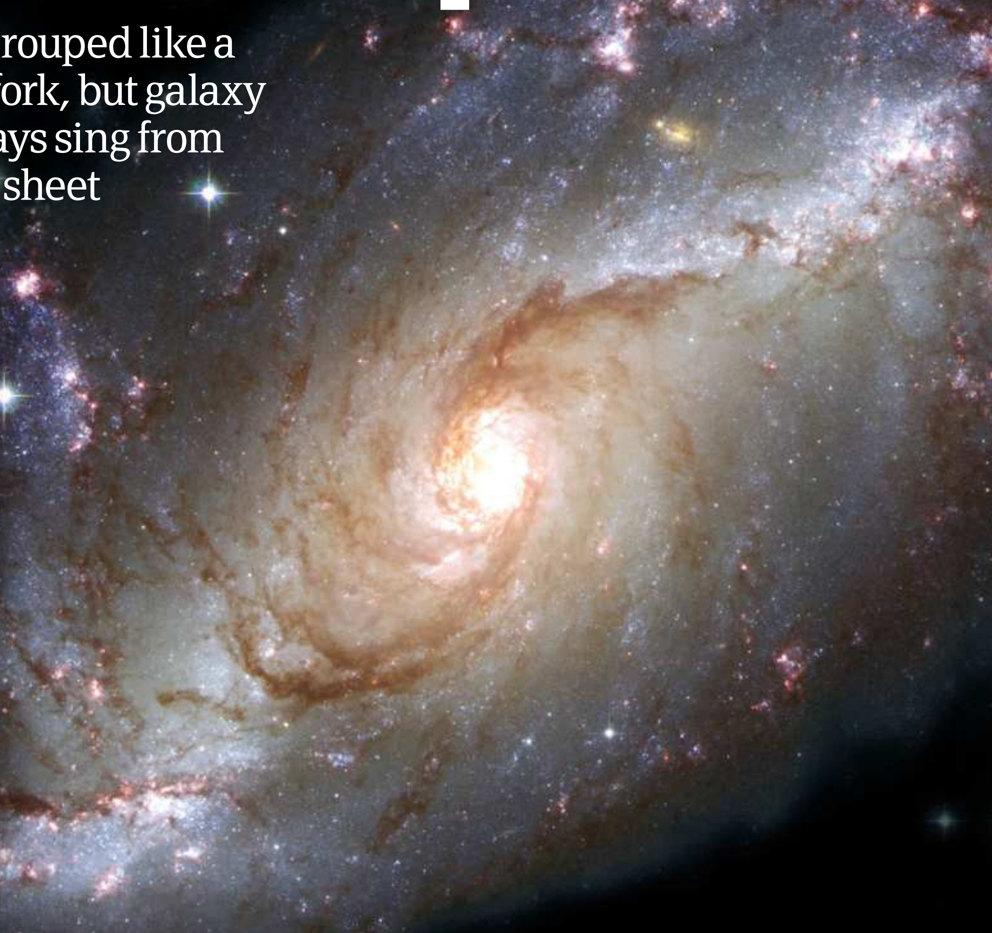
"Stellar black holes form when large stars collapse"



Dark lanes of dust crisscross the giant elliptical radio galaxy Centaurus A

Different types of galaxies explained

They might be grouped like a galactic tuning fork, but galaxy types don't always sing from the same hymn sheet

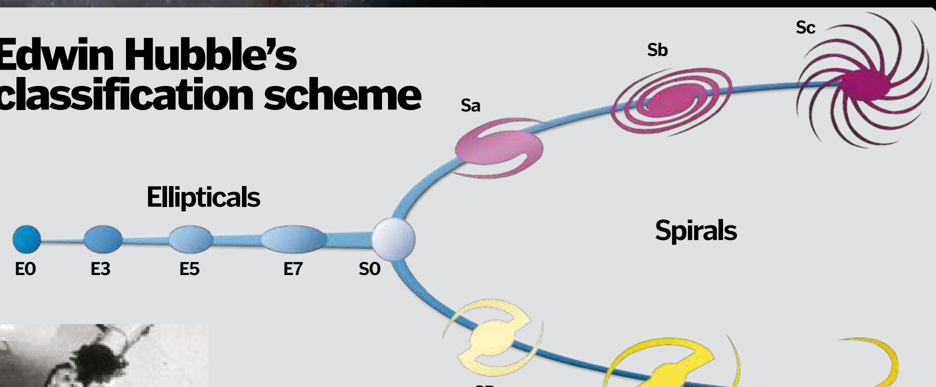


There are several different galaxy classification systems, but the most widely used is the Hubble Sequence, devised by the great Edwin Hubble in 1926 and later expanded upon by Allan Sandage among others. It's more commonly known as the Hubble tuning fork due to the shape the system represents in diagrammatic form.

Hubble's system was designed to demonstrate the various classifications of three main classes of galaxy broken down into elliptical, spiral and lenticular shapes. The latter is essentially an intermediate of the other two types. The tuning fork was erroneously thought that each galaxy type represented snapshots of the entire life span of galaxies, but it has since been demonstrated that this is not the case.

The most recent version of Hubble's tuning fork comes courtesy of the Spitzer Space Telescope's infrared galaxy survey made up of 75 colour images of different galaxies and includes a new sub-section of irregular galaxy types. You can find a full resolution image of this remarkable accomplishment at **http://sings.stsci.edu/Publications/sings_poster.html**. Thanks to the internet, anyone can try their hand at galaxy classification – simply visit the site **www.galaxyzoo.org** and join in alongside 150,000 of their other volunteers.

Edwin Hubble's classification scheme



Edwin Hubble Pioneer to the stars

No person in history has had a greater impact in determining the extent of our universe than Edwin Hubble. From proving that other galaxies existed to giving evidence that galaxies move apart from one another, Hubble's work defined our place in the cosmos. Shown above posing with the 48-inch telescope on Palomar Mountain, the Orbiting Space Telescope was named in memory of his great work.

Today a great controversy rages on about the rate of the universe's expansion, parameterised by a quantity known as Hubble's constant.

Types of galaxies

Galaxies can be categorised into these types…

Elliptical galaxies

On the far left of the Hubble Sequence lies the elliptical galaxy type. They show no defined features like the intricate dust lanes seen in classic spiral galaxy types, besides a bright core. Ellipticals are represented by the letter E, followed by a number that represents the ellipticity of its shape

Spiral types

Appearing flatter on the sky than an elliptical galaxy, spiral galaxies feature two or more spiral 'arms' that wrap around the galaxy core and are made up of vast lanes of stars. The upper half is populated with the standard spiral type, while the lower half contains 'bar' spirals. The twist of the spiral begins at the end of an extended bar

Lenticular galaxies

Where the handle of the tuning fork and the two spiral arms meet lie the lenticular galaxies. These galaxies feature aspects of both spiral and elliptical galaxies and didn't actually feature on Hubble's original sequence. They have a bright central bulge like an elliptical galaxy, but are surrounded by a structure not unlike a disc

DID YOU KNOW? *Uranus is tipped nearly 90 degrees on its side, likely caused by a collision with a protoplanet billions of years ago*

NASA's Hubble Space Telescope took this image of the Antennae galaxies, which began colliding a few hundred million years ago

Galaxy collisions

What happens when two galaxies collide?

When two galaxies cross paths, the chance of any stars colliding is almost zero. In fact, if the Milky Way collided with the nearby Andromeda galaxy, we would barely notice a thing on Earth. Instead, the multitude of dust and gas in each galaxy interacts and creates the characteristic spectacle. As the material inside the stars interacts gravitationally, newly formed gas clouds give birth to stars. Friction between the gases can cause numerous shock waves, which would also become instrumental in the formation of new stars.

Colliding galaxies usually take millions or even billions of years to merge. As they collide, tidal gravitational forces will rip the smaller of the two galaxies apart, scattering dust and stars. The inner core of the collision will heat up and radiate strongly, creating one of the brightest infrared objects in space. In this instance the larger galaxy will swallow the smaller one, but on some occasions the galaxies may pass through each other and emerge almost unharmed.

Joining forces

What happens when two galaxies collide?

1. First contact

The first signs of a galaxy collision will be a bridge of matter between the two galaxies, caused by gravitational forces.

2. Tidal tails

Long streams of gas and dust known as tidal tails spiral out of the collision as the material is thrown out.

3. Ripped apart

Gravitational forces pull the matter in all directions, creating shock waves throughout the cloud of gas.

4. A star is born

The core of the collision is subjected to intense frictional and gravitational forces, resulting in the formation of massive stars.

SUPERNOVAS

With more energy than a billion suns, a size greater than our solar system and the potential to destroy entire planets millions of miles away, some stars certainly know how to go out with a bang. Here we take a look at supernovas, some of the most powerful explosions in the universe

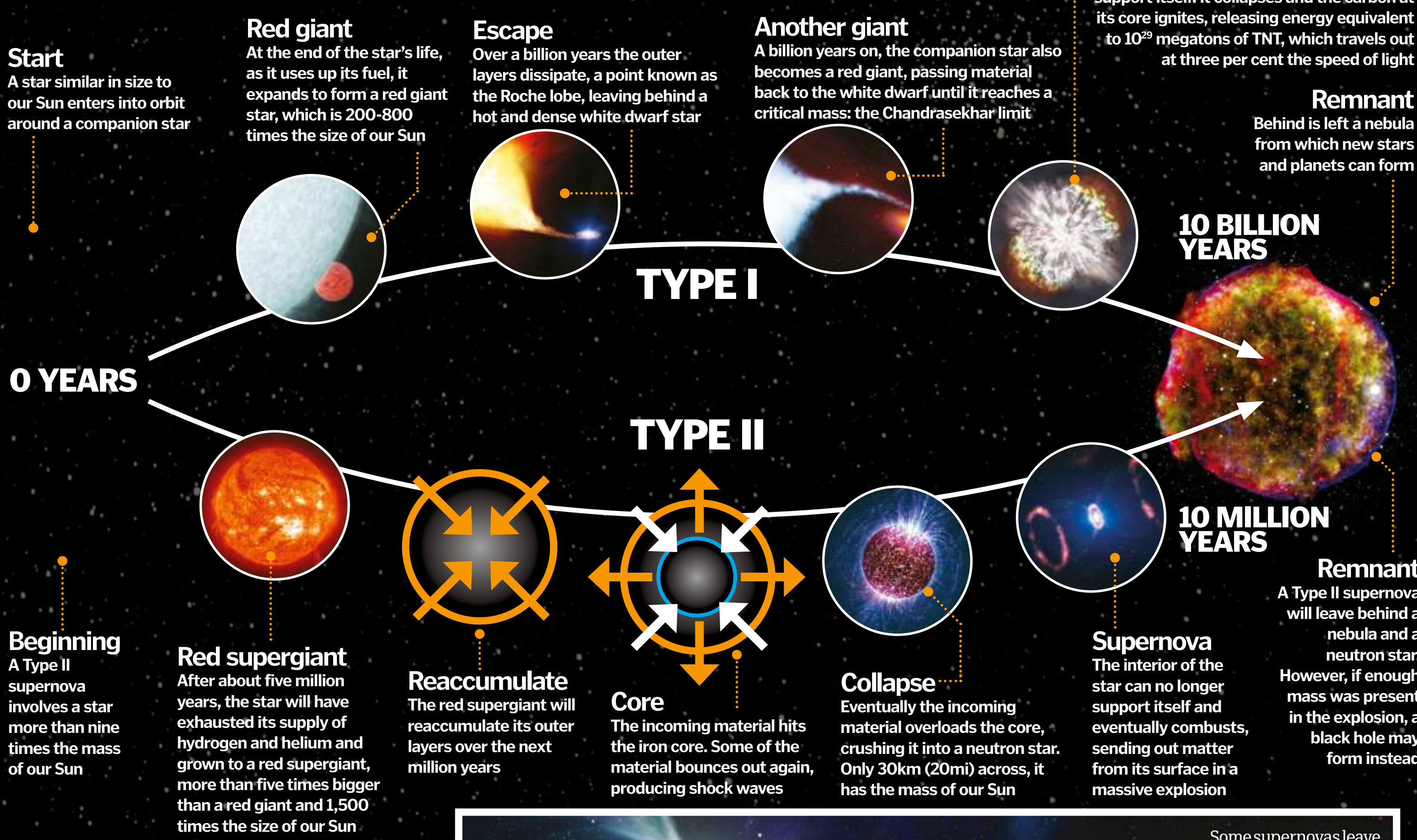
When we delve into certain realms of astronomy, the scale of events and objects are often impossibly large to imagine. If we think of planets like Earth and Mars we can at least get some sort of grasp on their size, as we can consider them relative to other bodies. As we get to bigger objects, like Jupiter and the Sun, our understanding gets somewhat muddled, but we can still comprehend how enormous they are by using Earth as a starting point (for example, the Sun is over 100 times the size of Earth). It's when we get to the larger celestial occurrences, like supergiant stars and black holes, however, that things really start to become unfathomable. In this article we'll be taking a look at one of these mammoth celestial events – supernovas – and we'll try to get our heads around just how large, powerful and crucial they are.

Supernovas have fascinated astronomers for millennia, appearing out of nowhere in the night sky and outshining other stars with consummate ease. The first recorded supernova, known today as SN 185, was spotted by Chinese astronomers in 185 AD and was apparently visible for almost a year. While this is the first recorded sighting, there have doubtless been many supernovas in preceding years that confounded Earth dwellers who were unable to explain the sudden appearance of a bright new star in the sky.

One of the most notable supernova events likely occurred about 340,000 years ago when a star known as Geminga went supernova. Although it was unrecorded, astronomers have been able to discern the manner of its demise from the remnant neutron star it left behind. Geminga is the closest known supernova to have exploded near Earth, as little as 290 light years away. Its proximity to Earth meant that it might have lit up the night sky for many months, casting its own shadows and

Countdown to a supernova

What events lead up to the explosion of the two known types of supernova?



Images © ESO/L Calçada/JPL-Caltech/ESA/HST

Some supernovas leave behind spinning neutron stars known as pulsars

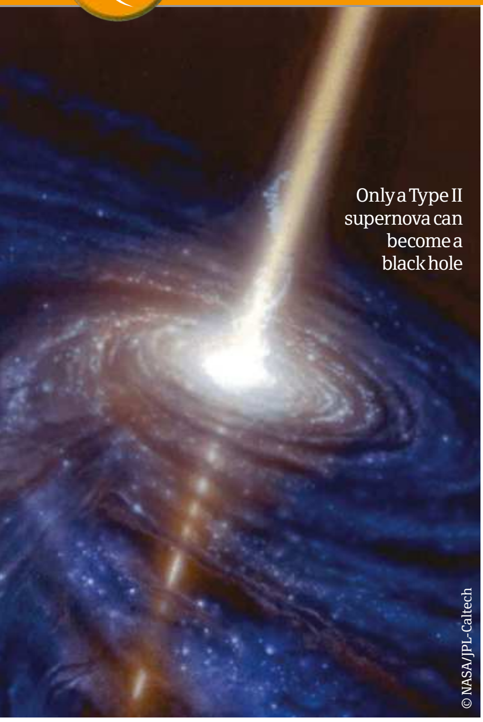
© NASA/JPL-Caltech

> *"Geminga is the closest known supernova to have exploded near Earth, as little as 290 light years away"*

rivalling the Moon for brightness, turning night into day. So bright and large was this supernova that the ancients would have seen the light of it stretching from horizon to horizon. Left behind after this supernova was a neutron star rapidly rotating at about four times a second, the nearest neutron star to Earth and the third largest source of gamma rays to us in our observations of the cosmos. Other notable stellar explosions include Supernova 1987A, a star located in the Large Magellanic Cloud that went supernova in 1987. This originated from a supergiant star known as Sanduleak -69°202. It almost outshone the North Star (Polaris) as a result of its brightness, which was comparable to 250 million times that of the Sun.

It is a testament to the scale of these explosions that even ancient civilisations with limited to no astronomical equipment were able to observe them. Supernovas are bright not only visually but in all forms of electromagnetic radiation. They throw out x-rays, cosmic rays, radio waves and, on occasion, may be responsible for causing giant gamma-ray bursts, the largest known explosions in the universe. It is by measuring these forms of electromagnetic radiation that astronomers are able to glean such a clear picture of the formation and demise of supernovas. In fact, it is estimated that 99 per cent of the energy that a supernova exerts is in various forms of electromagnetic radiation other than visible light, making the study of this invisible (to the naked eye at least) radiation incredibly important, and something to which many observatories worldwide are tuned. Another type of stellar explosion you may have heard of is a nova. This is similar in its formation to a supernova, but there is one key difference post-explosion: a supernova obliterates the original star, whereas a nova leaves behind an intact star somewhat similar to the original progenitor of the explosion.

Our understanding of the universe so far suggests that pretty much everything runs in cycles. For



Only a Type II supernova can become a black hole

© NASA/JPL-Caltech

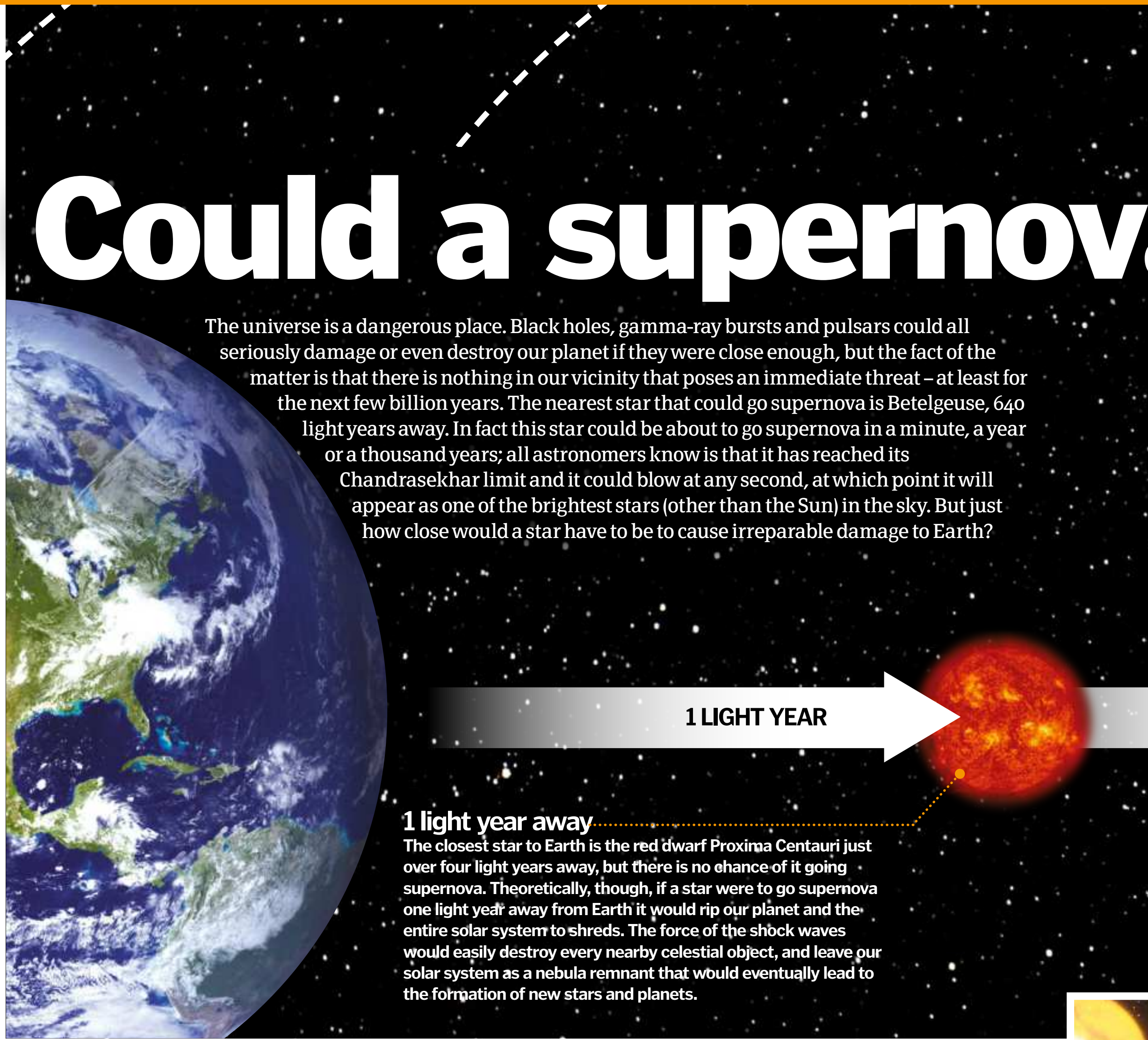
example, a star is born from a cloud of dust and gas, it undergoes nuclear fusion for billions of years, and then destroys itself in a fantastic explosion, creating the very same dust and gas that will lead to the formation of another star. It is thanks to this cyclic nature of the universe that we are able to observe events that would otherwise be extremely rare or nonexistent. If stars were not constantly reforming, there would be none left from the birth of the universe 13.7 billion years ago.

As destructive as they may be, supernovas are integral to the structure and formation of the universe. It is thought that the solar system itself formed from a giant nebula left behind from a supernova while, as mentioned earlier, supernovas are very important in the life cycle of stars and lead to the creation of new stars as the old ones die out. This is because a star contains many of the elements necessary for planetary and stellar formation including large amounts of helium, hydrogen, oxygen and iron, all key components in the structure of celestial bodies. On top of these, many other elements are thought to form during the actual explosion itself.

There's no doubt that supernovas are one of the most destructive forces of the universe, but at the same time they're one of the most essential to the life cycle of solar systems. As we develop more powerful telescopes over the coming years we will be able to observe and study supernovas in more detail, and possibly discover some that do not fall into our current classification of Type I or Type II. The study of supernovas alone can unlock countless secrets of the universe, and as we further our understanding of these colossal stellar explosions we'll be able to learn more about the cosmos as a whole.

Could a supernov

The universe is a dangerous place. Black holes, gamma-ray bursts and pulsars could all seriously damage or even destroy our planet if they were close enough, but the fact of the matter is that there is nothing in our vicinity that poses an immediate threat – at least for the next few billion years. The nearest star that could go supernova is Betelgeuse, 640 light years away. In fact this star could be about to go supernova in a minute, a year or a thousand years; all astronomers know is that it has reached its Chandrasekhar limit and it could blow at any second, at which point it will appear as one of the brightest stars (other than the Sun) in the sky. But just how close would a star have to be to cause irreparable damage to Earth?



1 light year away

The closest star to Earth is the red dwarf Proxima Centauri just over four light years away, but there is no chance of it going supernova. Theoretically, though, if a star were to go supernova one light year away from Earth it would rip our planet and the entire solar system to shreds. The force of the shock waves would easily destroy every nearby celestial object, and leave our solar system as a nebula remnant that would eventually lead to the formation of new stars and planets.

This image of the Crab Nebula shows the visible (red) and x-ray (blue) radiation left after a supernova

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All that remains…

What is left behind once a star goes supernova?

Inside a massive star, before it goes supernova, the nuclei of light elements like hydrogen and helium combine to form the basic constituents of other celestial bodies and even life (such as carbon and oxygen). Stars release these vital elements when they go supernova, providing the material for new stellar and planetary formation.

To date there are roughly 300 known supernova remnants in the universe. Depending on the type and mass of a supernova (see the diagram on the previous page), the remnants left behind can be one of several things. In the vast majority of cases some form of nebula will be left behind. Inside this nebula will often be a spinning neutron star. The rate of spin of this neutron star, also known as a pulsar, depends on the original mass of the exploded star, with some pulsars rotating upwards of a thousand times per minute!

These highly dense stars contain the mass of the Sun packed into an area no bigger than the city of London. If the supernova remnant exceeds four solar masses (the mass of our Sun), due to an extremely heavy initial star or by more material accumulating around the remnant from nearby objects, then the remnant will collapse to form a black hole instead of continuing to expand.

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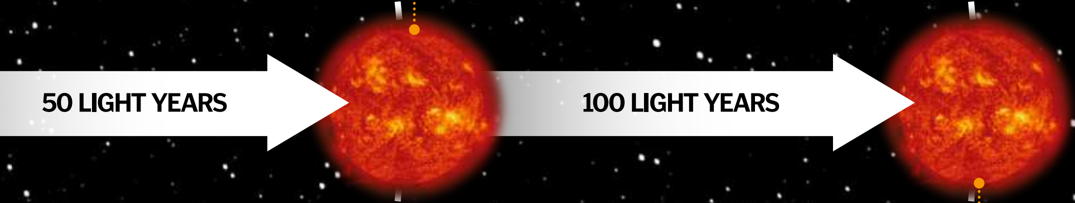
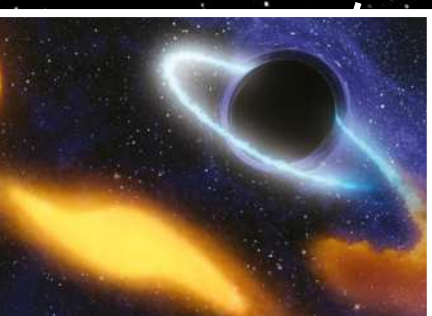
a destroy Earth?

50 light years away
In several billion years it is possible that a star closer to home will go supernova. If one did so about 50 light years from Earth, it is likely that it would shear the ozone off our planet, in turn also destroying the Earth's magnetic field. This would make our world all but uninhabitable.



100 light years away
At this distance a supernova poses no threat to Earth. The intensity of a supernova's energy dissipates exponentially, so other than observing a bright star in the night sky we would experience no effect on Earth. The closest star to Earth that could go supernova is Betelgeuse, 640 light years away, so it poses no threat to us.


A black hole can be left behind after a supernova if the star or remnant had a high enough mass

The oldest supernova

Take a look at the remains of the first supernova to be recorded by mankind

Type Ia
The lack of a pulsar at the centre of the supernova remnant suggests that it was a Type Ia supernova

Earliest
First observed by Chinese astronomers in 185 AD, this supernova remnant known as RCW 86 is the remains of the SN 185 supernova

Size
RCW 86 is located 8,200 light years from Earth in the Milky Way galaxy and is estimated to be 50 light years across

SIZE OF A SUPERNOVA

How much energy does a supernova release?

1,000,000,000,000,000,000,000 yottajoules (10^{44} joules)
Energy released from a supernova

1,000 zettajoules (1 yottajoule)
Total energy from the Sun that reaches Earth in a year

1,000 exajoules (1 zettajoule)
Energy of the entire Earth's petrol reserves

1,000 petajoules (1 exajoule)
Estimated energy in the 2011 Japanese earthquake and tsunami

1,000 terajoules (1 petajoule)
Energy in 1 megaton of TNT

1,000 gigajoules (1 terajoule)
Approximate energy in a small nuclear bomb

1,000 megajoules (1 gigajoule)
Average energy in a lightning bolt

1,000 kilojoules (1 megajoule)
Approximate daily male energy intake

1,000 joules (1 kilojoule)
Explosion of less than 1g (0.03oz) of TNT

1 joule of energy
Flash of a camera

The search for alien life

Our galaxy could be the home to millions of different alien life forms, but how do we find them?

Virtually every part of our planet is teeming with life, and it would be extraordinary that life – even on the lowest microbial level – does not exist on planets beyond our solar system. On a statistical level, our Milky Way spiral galaxy has a diameter of 100,000 light years and contains between 200 and 400 billion stars, a quarter of which have planets orbiting them. Of them, there could be 500 million planets that move in the habitable zone that can sustain life like our own.

If an alien civilisation were to reach our level of technological ability, it seems only logical that they would beam out messages in search of other life forms. The main restriction is that energy, matter, or information cannot travel faster than the speed of light – which is 300,000 kilometres (186,411 miles) per second. A far-flung alien message might take some 75,000 light years to reach Earth. Indeed, at best the nearest habitable zone planet, called Gliese 581g, is around 20 light years away.

When Enrico Fermi looked at the odds of intelligent life evolving to our level of technology, he was surprised that we had not been contacted already. The Fermi paradox is that despite the probability of extraterrestrial life, we have no evidence of its presence. There are several answers to the Fermi paradox; it might simply be that we are alone and that our creation was a very rare series of events that has not been duplicated elsewhere. Intelligent life forms might have a tendency to die out through natural disaster or warfare, or they could have transcended our technology and use more sophisticated forms of communication that are currently beyond our means of detection.

Radio telescopes have mainly been used to listen for any regular 'alien' signals in a narrow radio bandwidth. Another possibility is that aliens might signal to us in the optical wavelengths using powerful laser beams. In 2006 the Planetary Society began searching for an extraterrestrial laser signal using a 1.8-metre (72-inch) reflecting telescope. Although it processes as much data in one second as all books in print, it has only detected a few pulses of light as it searches the northern hemisphere, and all of them have been ruled out as extra terrestrial signals.

Astrobiologists consider the possibilities of detecting alien microbial life through their biosignature. Extremophile Earth microorganisms have been found to survive and reproduce, which at least offers some hope to finding this type of microbial life elsewhere in the solar system. Astrobiologists are also working on mass

The Drake equation

American astronomer Frank Drake formulated the Drake equation in 1961, to estimate the number of possible intelligent extraterrestrial civilisations that might exist in our Milky Way galaxy

N The number of alien civilisations capable of transmitting signals into space, based on estimates in the rest of the equation

ne The number of planets that might potentially support living organisms

fi The fraction of planets that develop can intelligent life

L The length of time alien civilisations might exist and send out communications

$$N = R^* \, f_p \, n_e \, f_l \, f_i \, f_c \, L$$

R* This estimates the yearly rate of star formations in the Milky Way galaxy

fp The fraction of star formations that support planetary systems

fl The proportion of planets that actually develop and nurture living organisms

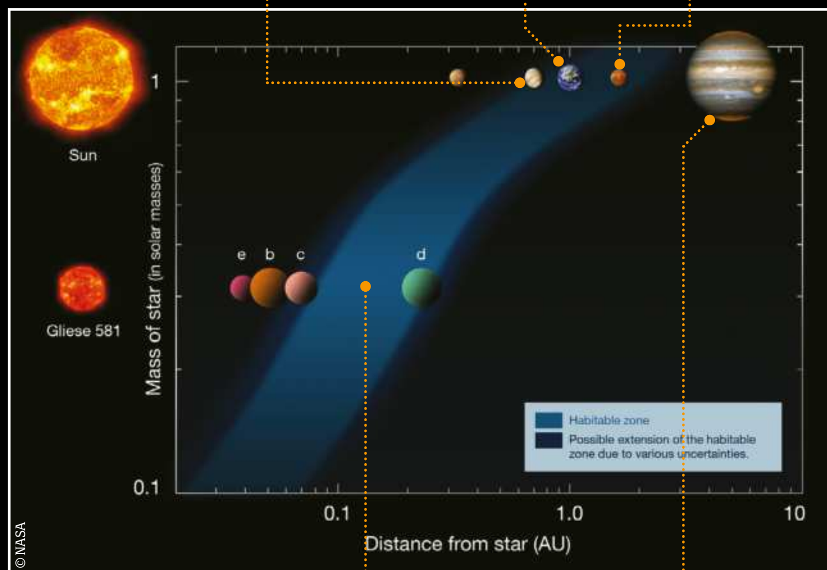
fc The number of alien civilisations that can create a technology to broadcast signals into space

Habitable zones…
…and where we are looking

1. Venus
Outside the inner boundary of the HZ – too hot (460°C) to sustain life

2. Earth
Earth orbits in the centre of the habitable zone that surrounds the Sun

3. Mars
Mars is on the outer boundary of the HZ; further exploration will determine if it is or was in the HZ



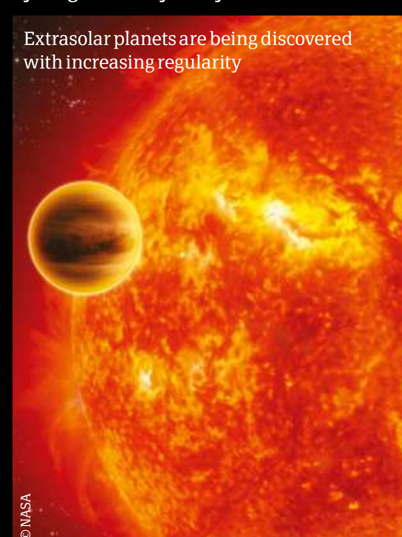
5. Extrasolar planets
Extrasolar planets, like Gliese 581d and g, are in an HZ that is closer to its smaller parent star

4. Jupiter
Although Jupiter and Saturn are outside the HZ, some of their moons might have primitive organisms living on them

The habitable zone (HZ) is a belt of space around a star that is either too hot or too cold for life to exist on any planet orbiting in this zone. The habitable zone is often called the Goldilocks zone after the children's story, referring to finding conditions for life that are "just right". The HZ varies according to the size, mass, luminosity and life-cycle of the parent star. Stars with a low mass and luminosity will have an HZ closer to them than a larger, brighter star. Unstable or short-lived stars are less likely to nurture life.

Primitive life might live outside the HZ, but it is very likely to be microbial or extremely different to 'life' as we know it. It is also postulated that life only occurs in star systems in the galactic habitable zone (GHZ), that are close enough to the galactic centre to form Earth-like planets but far enough away from fatal levels of radioactivity. The GHZ of our galaxy is about 6,000 light years wide and 25,000 light years from the centre.

SETI research concentrates its efforts on the newly discovered extrasolar planets in their respective habitable zone, and radio telescopes concentrate on listening to transmissions between 1,420 MHz (21cm) emissions from neutral hydrogen and 1,666 MHz (18cm) emissions from hydroxyl. This quiet range of the electromagnetic spectrum, nicknamed the water hole, is a logical place for water-based life to send signals as hydrogen and hydroxyl form water.



Extrasolar planets are being discovered with increasing regularity

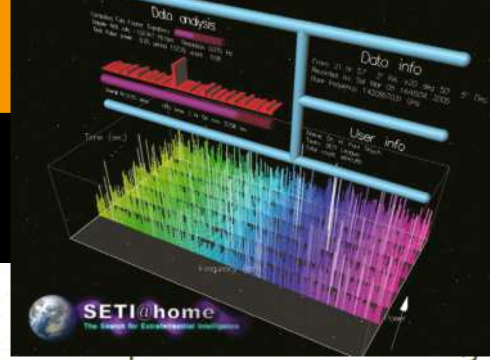
spectrometers and high-energy x-rays to detect life that does not consist of RNA, DNA or proteins.

Meteorites have been closely examined to see if they contain evidence of alien life forms. The Allan Hills 84001 (ALH84001) meteorite, which is thought to have come from Mars 13,000 years ago, was declared by David McKay to contain minute traces of fossilised bacteria. This hit the headlines in 1996, but terrestrial contamination and non-biological processes have been given as alternative explanations. Microfossils in carbonaceous meteorites were also discovered by astrobiologist Richard B Hoover in March 2011.

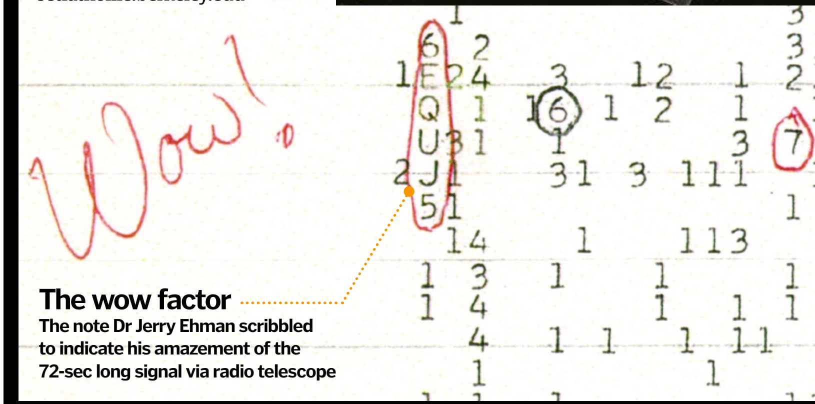
SETI (Search for Extraterrestrial Intelligence) research has also had several false alarms, the most famous being the so-called 'Wow' signal received in 1977 by the Big Ear radio telescope at the Ohio State University. Dr Jerry Ehman was so impressed by the 72-second long signal originating from the constellation Sagittarius, he wrote "Wow!" next to the alphanumeric code 6EQUJ5 on the printout. It has never been detected again and might have been created by a terrestrial signal.

Until recently, we were not sure that star systems hosted Earth-like planets. Since October 1995 when a Hot Jupiter extrasolar planet was found in the Pegasus constellation, 50 light years away, hundreds of extrasolar planets have been discovered. NASA's Kepler spacecraft was launched in 2009 to search for Earth-sized planets in the habitable zone of star systems up to 3,000 light years away, which are on the same galactic plane as Earth. So far, it's discovered 54 planets orbiting in the habitable zone of its parent planet. Now these planets have been identified, work is being carried out to find oxygen and other chemical signatures that might indicate that they actually harbour life on them.

When, or if, we find primitive life or contact intelligent ET life depends on whether there is life to find. Throughout our search, we need to take into account exotic or advanced ET life forms that might be unrecognisable to us.



For more information about SETI@home, visit the website http://setiathome.berkeley.edu



The wow factor
The note Dr Jerry Ehman scribbled to indicate his amazement of the 72-sec long signal via radio telescope

What is SETI?

SETI (Search for Extraterrestrial Intelligence) is conducted by several organisations to detect extraterrestrial life. SETI@home is unique because instead of using a huge supercomputer purpose-built to analyse the data collected by a specific radio telescope, it uses internet-connected computers to create a virtual supercomputer.

SETI@home software works as a screensaver, which borrows your computer when you're not using it. It collects the data in small chunks from the internet, analyses it and then sends the results back to SETI@home. The digital data is taken piggyback from the Arecibo telescope. The network is linked to 456,922 active computers worldwide and is run by the Space Sciences Laboratory at the University of California. Despite the equivalent of 2 million years of computing time, it has yet to come across an unambiguous ET signal. A weak signal was observed from SHGb02+14a between the Pisces and Aries constellations at the 1420MHz frequency. There is no star system observable at this location and could have been produced by a technical glitch.

The SETI Institute is a non-profit organisation that covers virtually every aspect of SETI research. In the Nineties, it ran Project Phoenix using the Parkes radio telescope in Australia and a radio telescope in West Virginia, to study 800 stars within a 200 light year range of Earth. No ET signals were found.

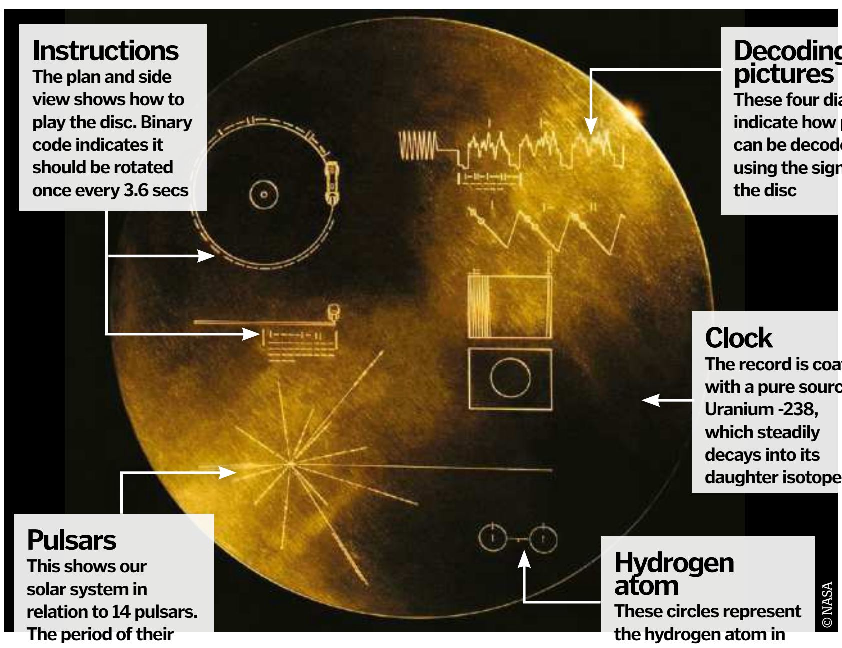
The Arecibo message

The Arecibo radio telescope in Puerto Rico sent the first message to be deliberately beamed into space on 16 November 1974. The 1,679 binary-digit message was sent over a three-minute long period on the 2,380MHz radio frequency. Data such as DNA was aimed at the Messier 13 star cluster in the Hercules constellation, and will take 25,000 years to reach it.

Dreamstime

The Golden Record

The Voyager 1 and 2 spacecraft were launched in 1977 to explore the outer planets of the solar system and beyond. Voyager 1 is in interstellar space, while Voyager 2 is in the Heliosheath. Like a message in a bottle, they carry a 30cm (12in) diameter gold-plated copper disc. The disc contains greetings from Earth in 55 different languages and a range of Earth-related pictures, sounds and music chosen by a committee headed by the late astronomer Carl Sagan.



Instructions
The plan and side view shows how to play the disc. Binary code indicates it should be rotated once every 3.6 secs

Decoding pictures
These four diagrams indicate how pictures can be decoded by using the signal from the disc

Clock
The record is coated with a pure source of Uranium -238, which steadily decays into its daughter isotopes

Pulsars
This shows our solar system in relation to 14 pulsars. The period of their pulsations is given in binary code

Hydrogen atom
These circles represent the hydrogen atom in its two lowest states, acting as a time reference for the data

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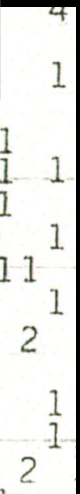


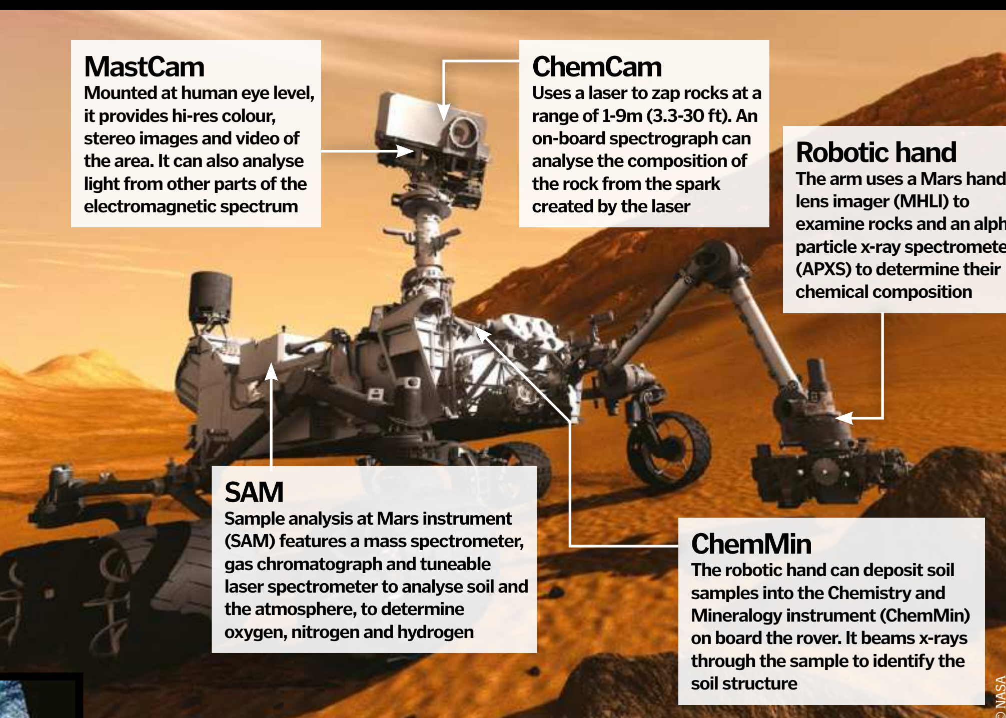
Life on Mars

Mars was regarded as the home of human-like life until the Sixties, when the Mariner space probes showed it was a cratered planet with an atmosphere consisting of carbon dioxide (CO_2). The 1972 Mariner 9 mission did, however, show evidence of running water on the surface of the planet in the past.

In 1976, the Viking 1 and 2 spacecraft landed on Mars to put soil samples in a nutrient labelled with radioactive carbon-14. If any organism were present, it would digest the nutrient and give off recognisable gasses. However, results gave no clear sign of life.

Since their arrival on the Red Planet in 2004, the two Mars Exploration rover craft Spirit and Opportunity have all but confirmed that liquid water did flow on the surface of Mars several hundred million years ago. This indicates that life could have existed on Mars and might still be hidden beneath its surface.

NASA's Mars Science Laboratory, which consists of the Curiosity rover, analyses samples of Martian soil in great detail to find out for certain whether or not microbial life is present or if it can live in this environment and the role of water on the planet.



Life in the solar system

Several surprising places might harbour life beyond Mars. Hopes that the brew of methane, ammonia, hydrogen and water stirred by lightning in Jupiter's atmosphere would create life have been considered and dismissed. Now, as a result of two Voyager probes passing Jupiter in 1979, Europa, one of Jupiter's moons, is discovered to have an icy surface with a liquid water ocean underneath it. If heat is being vented at the bottom of the ocean, it could well promote the existence of microbial life.

Two moons of Saturn are also regarded as having oceans of water beneath their surface. NASA's Cassini spacecraft found that the 505km (313mi) diameter Enceladus has potential for life, due to water indicated by geysers of ice particles that jet from its surface. The 5,150km (3,200mi) diameter Titan has a smoggy atmosphere and ethane/methane lakes that may contain primitive organisms and that may indicate similar conditions to those on Earth millions of years ago.

Titan, whose Earth-like conditions could harbour primitive life

INTERVIEW

Philip Plait

Dr Philip Plait is an astronomer, author and blogger who covers all things universe-related in the Bad Astronomy blog

Q: Have you personally taken part in any search for alien life projects?

Philip Plait: No, but some years ago, when I was working on Hubble, I tried to get pictures of extrasolar planets – which, unfortunately, didn't work out. However, I've written numerous times on astrobiology topics, and it was the subject of an episode of a TV show I filmed.

Q: What are our chances of finding aliens?

PP: I know Seth Shostak of SETI has said that if aliens are out there and broadcasting using radio, we'll detect them in the next 25 years or so. There are a lot of assumptions in there, but it's an interesting calculation. I can't say for sure when it will happen, of course, but I'd sure like to be around if and when it does. One way or the other, though, I doubt it'll be via spaceships. It's far more likely that it'll be through some sort of light-speed communication method, like radio.

Q: Where do you think we should be looking?

PP: Everywhere! It might make sense to look at stars like the Sun to start with, since we know they can have planets and live long lives, enough time for intelligent life to develop. But one thing we know about nature is that it's more clever than we are, so I wouldn't limit the search at all.

Q: Do you think there's intelligent life out there, or is it likely to be microbial?

PP: Given what we know now – there are billions of Sun-like stars out there, and a good fraction of them have planets – I suspect there's lots of life in the Milky Way. But out of the 4.5 billion years the Earth's been around, it had basically gloop living on it for more than half that time. So I think if we ever travel to other planets, that's what we'll find mostly. But open this up to the "whole universe", and I'm thinking the answer leans towards yes, there are other civilisations out there. The number of stars is in the quintillions. That's a pretty good number to start with.

Q: What is the current status of ET searching?

PP: SETI's Allen Telescope Array is currently mothballed due to lack of funds, and that's not good. The technology is advancing rapidly, which is why Seth gave that 25-year timeframe. I'm hoping that they'll get the ATA running again soon.

Q: What current or future mission most excites you about the search for ET?

PP: Right now, Kepler is the best thing going: it may very well detect planets the mass and size of Earth orbiting their stars at the right distance to have liquid water on their surface. That's not finding life, but it would be a major step in that direction. I don't think any astronomer would bet against it, but knowing there's another possible Earth out there would be motivating.

Q: Do you think aliens may have visited/communicated with us in the past?

PP: In recent history, I doubt it – the evidence simply isn't there. But time is very long and deep; any civilisation may well have come here a long time ago…

A TO Z OF THE GALAXY

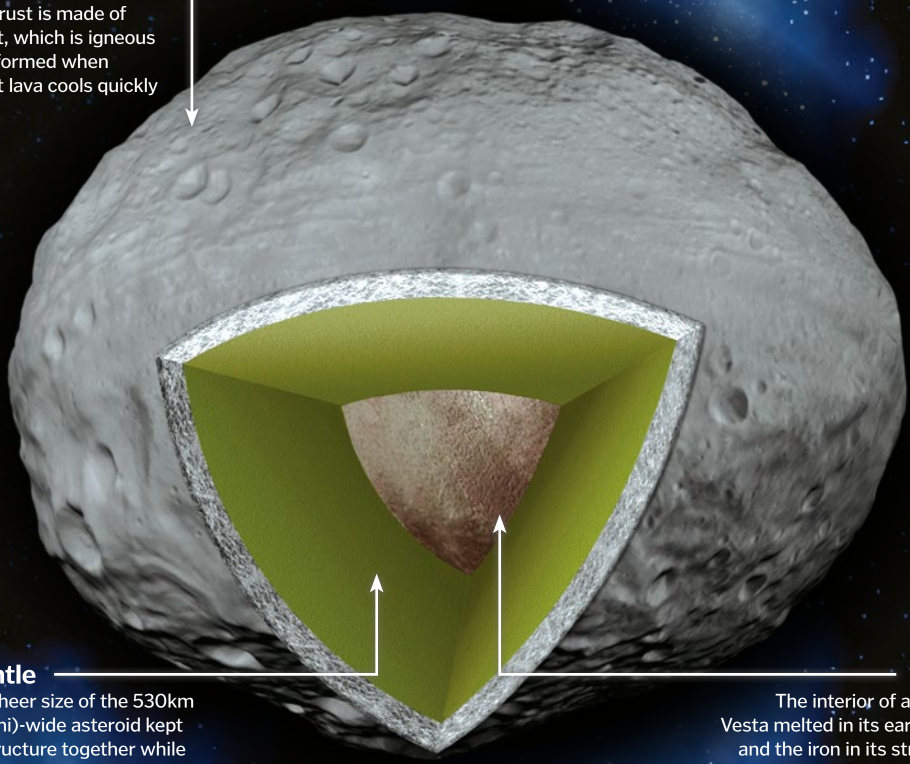
Come on a journey through the cosmos

Asteroids

There are millions of asteroids in our galaxy, ranging in size from less than a kilometre (0.6 miles) across to 950 kilometres (590 miles). The ones in our Solar System are mainly found in the Asteroid Belt between Mars and Jupiter and are made mostly of solid rock. However, they have been known to leave the belt. Asteroid groups called Atens, Amors and Apollos cross close by the Earth's orbit and can occasionally hit Earth. An asteroid would have to be at least 25 metres (82 feet) across for it to survive the journey through the Earth's atmosphere without burning up. NASA estimates that a car-sized asteroid makes it through the atmosphere every year, but will usually disintegrate before hitting the Earth. Back in 2001, NASA orbiter NEAR Shoemaker landed on the surface of near-Earth asteroid 433 Eros. Despite not being part of the original plan, Shoemaker became the first manmade object to land on an asteroid.

Inside an asteroid

What makes up an asteroid?



Barred spiral galaxy

Barred spiral galaxies are made up of an incredibly dense bar of stars, dust and gas surrounded by a number of spirals made up of less densely packed stars and dust. The Milky Way is a barred spiral galaxy and our Solar System sits on the Orion spur, a breakaway of Perseus, the western spiral arm of the galaxy.

The Milky Way contains more than 200 billion stars

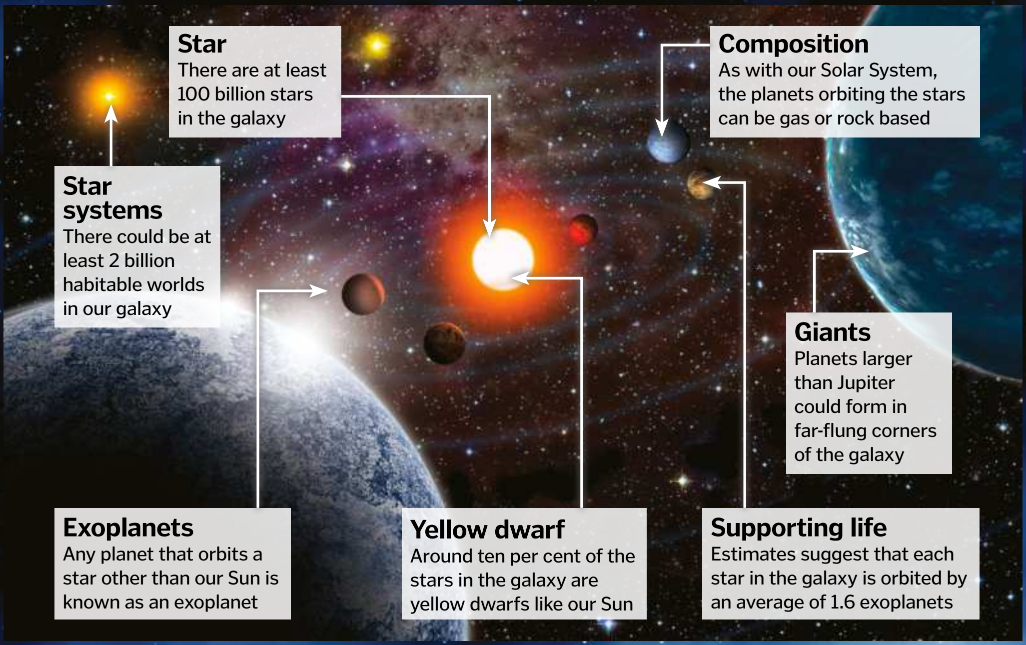
Dark matter

The existence of dark matter is currently theoretical based on the way visible matter behaves. As it doesn't reflect, give out or absorb light, scientists are still unable to detect it. Dark matter is estimated to make up around 26 per cent of the mass of the galaxy, which is over six times greater than the mass of visible matter. Scientists at CERN hope to create dark matter particles in the Large Hadron Collider, but even then they could only know of their existence due to the loss of energy inside the machine.

Dark matter around a galactic cluster is represented here in blue

Exoplanets

An exoplanet is a planet in a solar system other than our own. One of the closest, Gliese 581g, is only 20 light-years away. Over 1,700 such planets have already been discovered, but scientists believe that there could be at least 160 billion in our galaxy alone. According to estimates, around 2 billion of these could potentially be capable of supporting life.



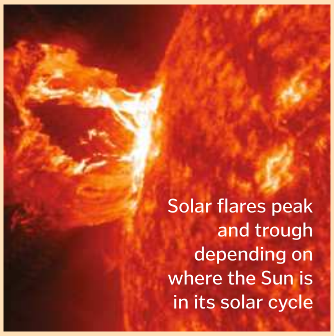
Comet

Despite looking rocky, comets are balls of ice, dust and gas. It is believed they contain remnants from the Big Bang, which is why the Rosetta mission to land on a comet was so important. Comets give off a coma of gas that looks like a tail. They usually stay in the Oort Cloud at the edge of the Solar System.

An illustration of the comet Churyumov-Gerasimenko

Flares

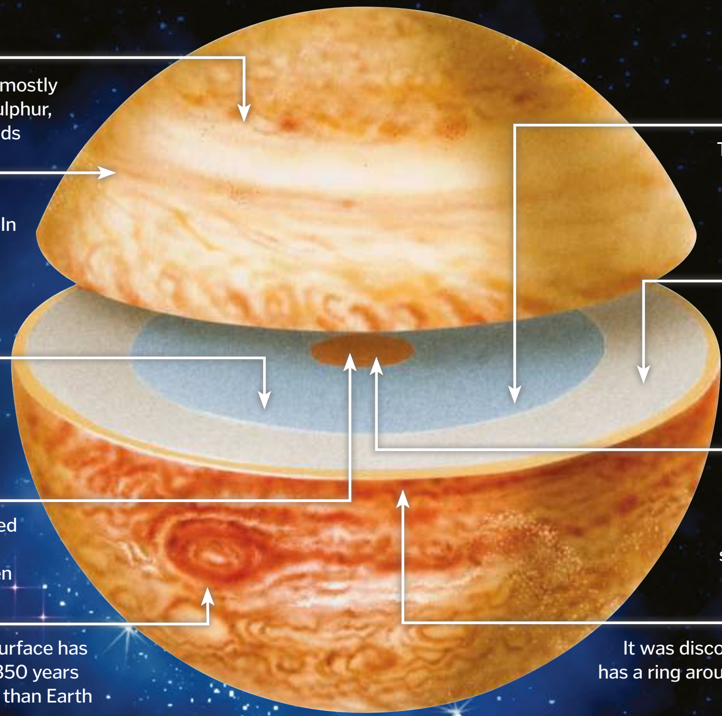
Flares occur when magnetic energy on the Sun (or other stars) builds up, and is suddenly released, heating the surrounding plasma to temperatures of up to 100 million degrees Celsius (180 million degrees Fahrenheit). The three stages of a solar flare are the precursor stage, where the energy starts to build up; the impulsive stage, where the particles begin to accelerate and are emitted; and finally the decay stage, where the flare subsides. Earth is protected from the radiation emitted in flares by its magnetic field, but high solar-flare activity is capable of knocking out our radio signals because the X-rays emitted disrupt the ionosphere.



Solar flares peak and trough depending on where the Sun is in its solar cycle

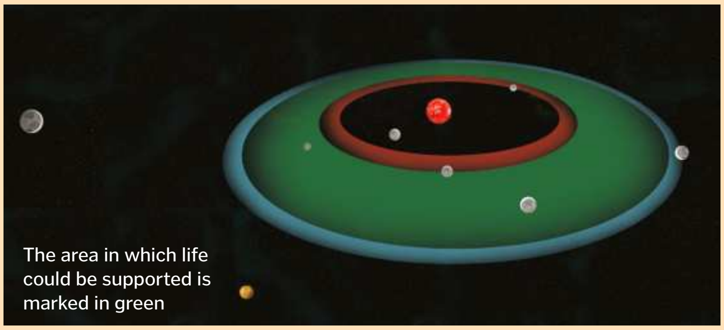
Gas giants

Gas giants like Jupiter and Saturn are found in star systems across the galaxy. Some are known as "hot Jupiters" because although they resemble our neighbourhood's largest planet, they orbit much closer to their parent stars. All gas giants have thick atmospheres of hydrogen and helium, surrounding either rocky or metallic cores.



Habitable zone

Also known as the Goldilocks zone, the habitable zone is an area around a star that could sustain life. Like in Earth's case, it needs to be close enough to the star to provide heat to its inhabitants but not so close it boils water on the planet. The exoplanet system around star Gliese 667C is thought to have three planets orbiting in its habitable zone.



The area in which life could be supported is marked in green

Jets

Jets are streams of particles emitted by black holes. Sagittarius A*, the black hole at the centre of our galaxy, fires a jet into the galaxy once a day. It is thought they are the result of objects such as asteroids falling into the black hole and being expelled. The jets run into gas around the black hole and produce X-rays, so we are able to detect them using telescopes such as Chandra.

Jets of particles streaming either side of Sagittarius A*

Interstellar medium

The area between stars is the interstellar medium, found in regions where the solar wind streaming from a star is countered by the interstellar wind. The gas is about 75 per cent hydrogen, 25 per cent helium and is found in the form of cold hydrogen clouds or hot ionised hydrogen. Having been launched in 1977, NASA announced that their Voyager 1 probe had reached the interstellar medium in August 2012.

The interstellar medium begins when a star's solar wind drops at the termination shock boundary

Kepler's laws

Johannes Kepler's laws of planetary motion describe how planets orbit stars. The first law explains why the orbit of the planets in our Solar System are elliptical, while the second and third laws provide the model for astrophysicists to map where planets will be at any one time. Despite being formulated from data collected by his mentor Tycho Brahe in the early 17th Century, the laws still hold up today.

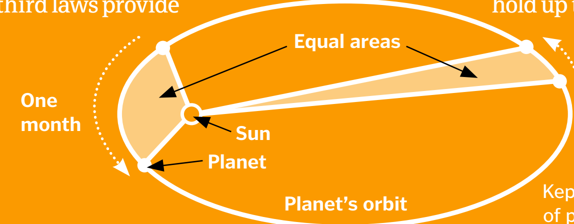


Diagram demonstrating Kepler's second law of planetary motion

Local Group

Our galaxy is part of a group of at least 30 galaxies that are known as the Local Group. Around 20 of these are bright galaxies, the brightest of which are the Milky Way and Andromeda, our nearest neighbour. The Local Group is spread over 10 million light years, but this will inevitably change as it is projected to get drawn into the Virgo Cluster at some point in the future.

The Triangulum galaxy (M33) is the third-largest in our Local Group after the Milky Way and Andromeda

Multiple-star system

We may think planets with two suns are only found in *Star Wars*, but they do exist in our galaxy. Planets that orbit more than one star are rare as the stars' combined heat makes it much harder for planets to form. Therefore they tend to form further out than normal and then move closer toward the stars. Studies suggest that planets in binary star systems are common.

Kepler-35b orbits its two host stars once every 131 days

Nebulae

Nebulae are among the most striking images in the galaxy. Incredible visions such as the Horsehead nebula or the Rosette nebula form when the interstellar medium (see 'I' for further information) collapses. This causes the interstellar dust, hydrogen and helium to draw together due to gravitational attraction. As the nebula forms, its gravitational attraction increases, which draws even more gas and dust toward it. The core of the nebula begins to heat up and nuclear fusion takes place. That reaction sends radiation outward to the edge of the nebula, which ionises the gas and turns it into plasma. These are the ingredients needed for a protostar to become a star. Therefore, the study of nebulae is key for scientists hoping to discover how our Solar System was formed. The dark clouds of a nebula can be quite hard to see, but scientists can sometimes get lucky, as in the case of the Horsehead nebula, which is backlit by the star Sigma Orionis. Nebulae also form at the other end of the scale. When a Sun such as ours dies it turns into a red giant star, which eventually burns the last of its fuel and becomes a planetary nebula.

The Horsehead nebula is part of the Orion constellation

Open clusters

This is a loosely bound group of young, hot stars is called an open cluster. They form inside a molecular cloud, which is a collection of hydrogen molecules and is where every star in the galaxy begins to form. They tend to stay inside their molecular cloud until the radiation they give off dissipates it. As they are so loosely bound together, open clusters are prone to losing members to other systems.

The Pleiades open cluster is bright enough to be seen by the naked eye from Earth

Protoplanetary disks

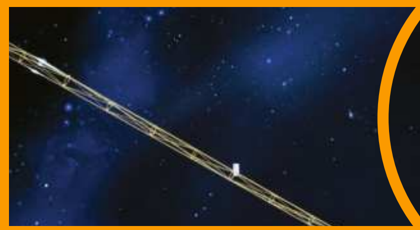
It is thought that our Solar System, as well as most others in the galaxy, formed thanks to a protoplanetary disk. These start out as a protostar, which is a body that has the potential to become a star but is not yet hot enough, surrounded by a molecular cloud. Gravitational forces cause the cloud to collapse and start spinning, causing material to clump together and form planets and asteroids.

The gaps in between the disk's rings are where planets begin to form

Quasar

A stunning representation of a quasar, one of the brightest objects in the universe

Quasars are the brightest objects in the universe, composed of streams of particles emitted by supermassive black holes. These particles exit the black hole at near the speed of light and have more energy than all the stars in their galaxy combined, releasing this as light energy. Although our galaxy doesn't contain a quasar, it's possible that it used to and could again when the Milky Way collides with Andromeda galaxy.



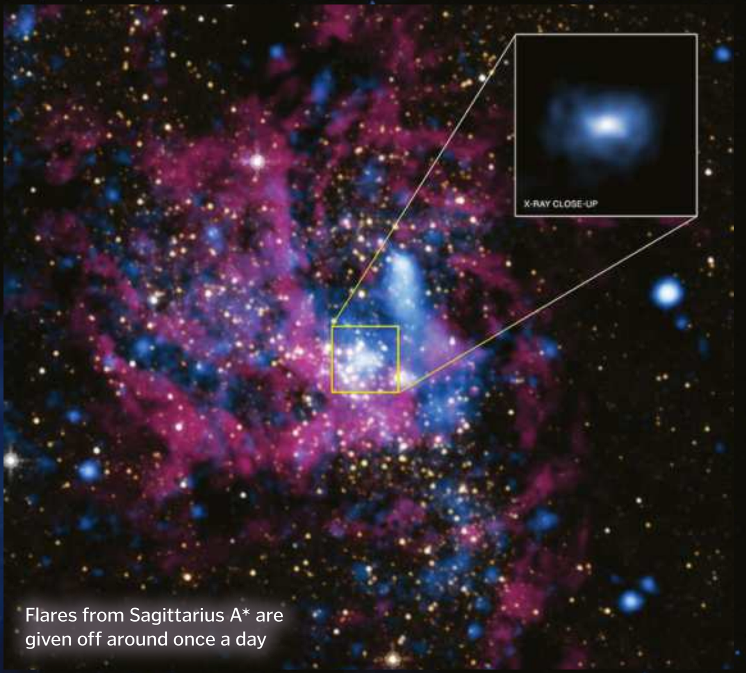
Plasma emanating from Saturn is detected in the form of radio waves

Radio waves

Stars such as our Sun emit electromagnetic radiation in the form of radio waves, which have the longest wavelength of any wave in the electromagnetic spectrum. This allows us to pick up the long-range signals, amplify them using huge dishes and learn more about objects in our galaxy. By viewing the galaxy through radio telescopes we can see further than ever before and detect far-flung pulsars and quasars.

Sagittarius A*

No A-Z of the galaxy would be complete without the mysterious object that sits at its very heart. Sagittarius A* is a supermassive black hole around which the entire galaxy revolves. Its mass is 4 million times greater than the Sun's and sits 26,000 light years from Earth. It is likely to have formed when a star collapsed in on itself, retaining all its mass but dramatically reducing in size. It will have become a supermassive black hole either by steadily acquiring matter or colliding with another black hole and combining. Almost every galaxy has a supermassive black hole at its centre, keeping all the various bodies orbiting around it thanks to its astonishingly powerful gravitational pull. Black holes are impossible to actually see as they suck in everything around them, including light. However, they can be spotted by the high-energy light produced by stars and gases in their vicinity. Having said that, some things do manage to escape from Sagittarius A*. Images from the Chandra and XMM-Newton observatories have shown incredible X-rays, gamma rays and flares being given off from the black hole. It can also be detected by observing the effects of its immense gravity on the surrounding area.



Flares from Sagittarius A* are given off around once a day

The Hubble telescope was launched in 1990 and has carried out nearly 4,000 observation programmes

Telescopes

Telescopes come in many forms, helping us study the galaxy. There is the Very Large Telescope (VLT) array, which combines its four 8.2-metre (26.9-foot)-wide mirrors to see 25 times farther than one alone. The Atacama Large Millimeter/submillimeter Array (ALMA) consists of 66 radio antennas that receive signals emitted billions of years ago, and we can't forget Hubble, currently orbiting Earth at 28,160 kilometres (17,500 miles) per hour.

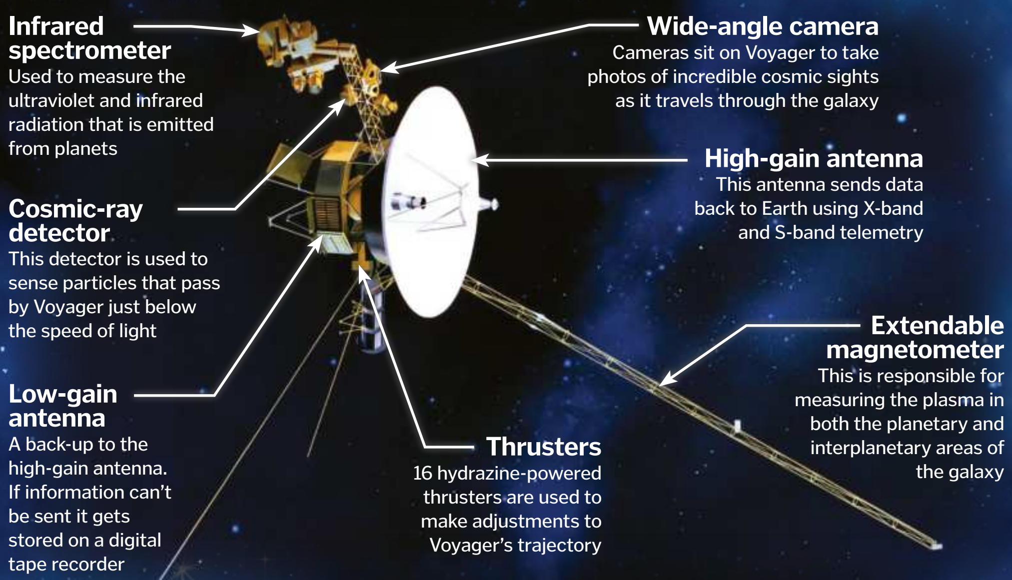
Ultraviolet radiation

If you've ever had sunburn, you are the victim of UV radiation from the Sun. Ultraviolet radiation is on the lower end of the electromagnetic spectrum, meaning that its wavelengths vibrate rapidly and can mess with our DNA. Our atmosphere mostly blocks UV radiation, however. When stars turn into white dwarfs they emit huge amounts of UV radiation that heat up the gaseous layers around them.

The Helix nebula is spewing UV radiation from its core as it dies

Voyager

Voyagers 1 and 2 were launched in 1977 with the brief of exploring Jupiter and Saturn. The two spacecraft returned amazing images of volcanoes on Jupiter's moon Io and Saturn's rings. Once they had mapped the two closest gas giants their mission was extended to travel farther than any manmade object had ventured before. Voyager 1 reached Uranus in January 1986 and Neptune in 1989. It then entered interstellar space in August 2012 and is transmitting data back to Earth about the unknown region between solar systems in our galaxy. Using technology developed nearly 40 years ago, Voyagers 1 are 2 are still successfully exploring the galaxy and providing data via the Deep Space Network, which is an array of radio antennas that allow data to be sent from incredible distances.



Wolf-Rayet star

When a star that is at least 20 times the size of our Sun burns out, it transforms into a red supergiant. If heavy elements manage to push their way out to the surface and cause winds to shoot gas out at incredible speeds, the supergiant becomes a Wolf-Rayet star. Only around 230 Wolf-Rayet stars that haven't detonated into supernova stage have been catalogued in our galaxy.

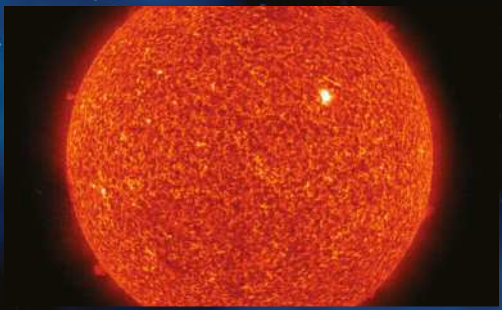
X-rays

X-rays are emitted from all kinds of galactic bodies, from stars to black holes. As virtually no X-rays are able to penetrate the Earth's atmosphere, NASA has had to send telescopes into space to detect them. They are especially useful to astronomers as they can be detected even when there is nothing visible for other telescopes to pick up. X-rays are the main type of radiation emitted from black holes.

Telescopes can pick up X-rays that give information on the location of black holes

Yellow dwarf

Our Sun is an example of a yellow dwarf, one of several classifications of star. These stars have a temperature range of 5,030 and 5,730 degrees Celsius (9,080 and 10,340 degrees Fahrenheit) and tend to live for around 10 billion years or so. At this point they turn into a red giant star and then collapse into a white dwarf. Our Sun has approximately 5 billion years before it turns into a red giant star.



Our Sun is one of the biggest known yellow dwarfs in the Milky Way galaxy

Z

The letter 'z' is the notation for redshift and blueshift. As wavelengths of the light spectrum change, so do the colours. If a star is moving away from us, the wavelength of its light is stretched out and becomes redder. If it is moving towards us, it appears bluer as the wavelengths get shorter. When z is positive the light is then shifted toward the red and if z is negative it has blueshifted.

We discover how far away stars are by the amount of redshift and blueshift they exhibit

ASTRONOMY

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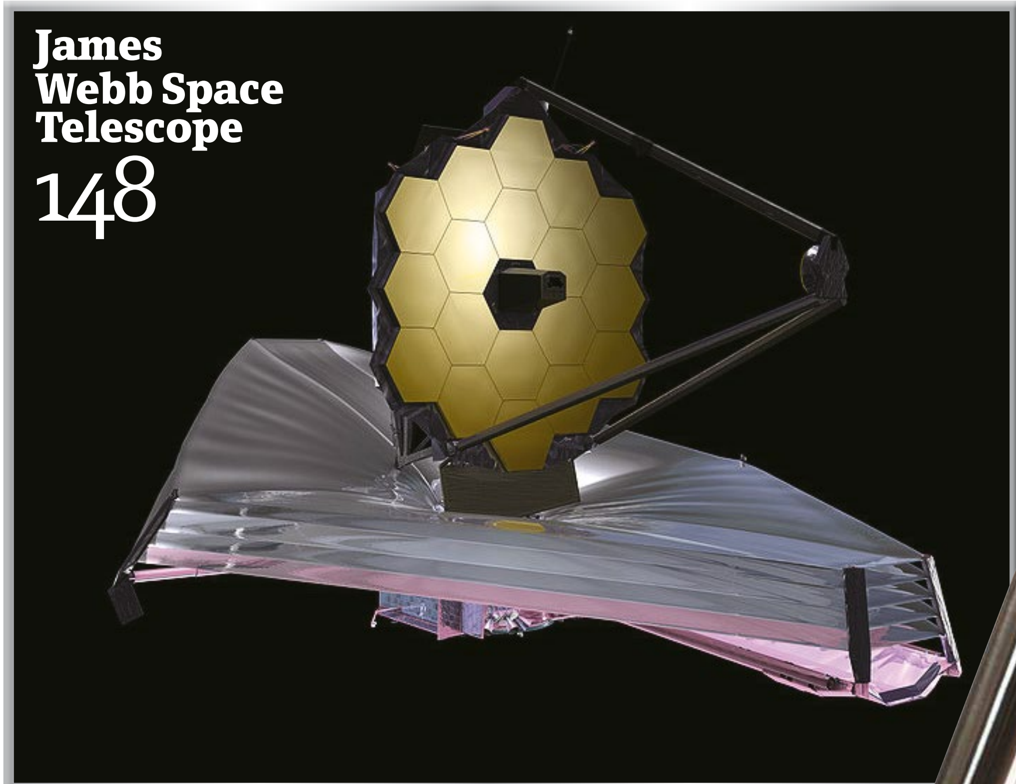
Telescopes



James Webb Space Telescope
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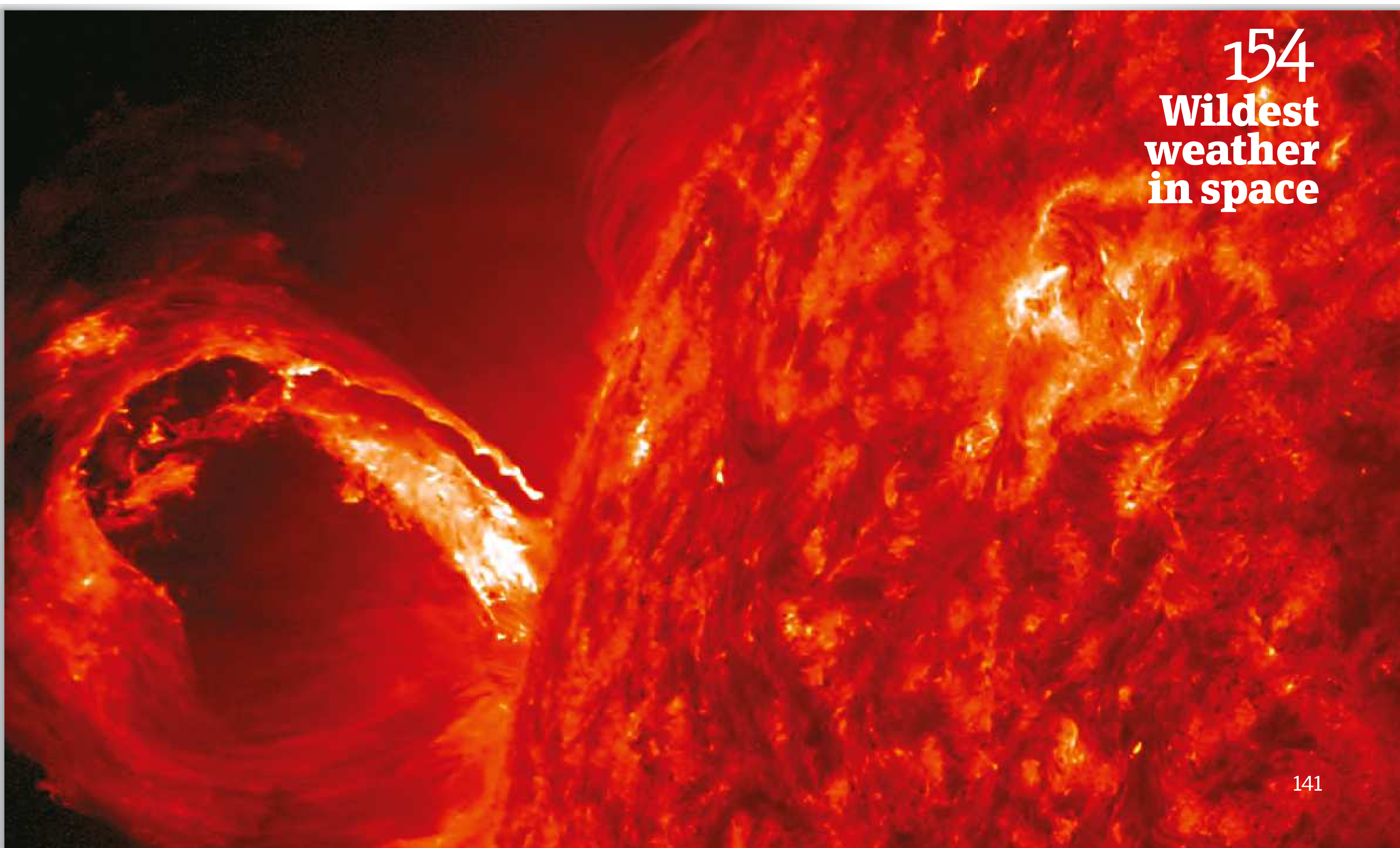
How far can we see into space?



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Wildest weather in space

Telescopes

The telescope was the first step in really opening up the universe for scrutiny…

Telescopes are all designed to do the same thing: collect and magnify light so that we can examine it. Practically speaking, we most often use them to observe the cosmos. There are three main types of scope: refractive, reflective and compound. Hans Lippershey is credited with inventing the first working telescope in 1608, which was a refracting type using lenses. Lippershey's invention was known as a Dutch perspective glass and probably consisted of a convex lens at the end and a concave lens as an eyepiece. Numerous other astronomers worked to improve upon this initial design, including Galileo Galilei and Johannes Kepler; Galileo's version of the refracting telescope was the first to be called a 'telescope', with Greek poet Giovanni Demisiani coining the name.

All refracting telescopes had one flaw, however: the lenses created chromatic aberration, resulting in a blurry image. To combat this, astronomers made telescopes with longer and longer tubes, among other designs, but these were hard to manoeuvre.

In 1668, Isaac Newton created the first reflecting telescope, which used mirrors to focus the light and avoided chromatic aberration. After Newton, Laurent Cassegrain improved on the reflecting telescope by adding a secondary mirror to reflect light through an opening in the primary mirror. The refracting telescope still held pull though because it was simply better at observing deep-sky objects as well as distant terrestrial objects. Since the lens was the issue, British inventor Chester Moor Hall came up with the achromatic lens in 1773.

The Herschelian telescope (made by William Herschel), a reflector built in 1778, did away with the secondary mirror by tilting the primary mirror slightly. Astronomers tried making more reflective mirrors to better optimise light. Advancements such as coating mirrors with silver and, later on, aluminium, allowed for reflective telescopes with ever-larger diameters to be built.

In 1930, German optician Bernhard Schmidt sought to create a hybrid telescope that took the best features of both refractive and reflective. The first compound, or catadioptric, telescope, had a primary mirror in the back of the telescope and a lens at the front. Later, a secondary mirror was added to create the Schmidt-Cassegrain model, and many variations followed. The compound telescope is the most popular design today.

Through the 20th Century telescopes began to be developed for other types of electromagnetic wavelengths, such as radio, gamma ray, X-ray and ultraviolet.

© ESO

The ESO's Very Large Telescope (VLT) actually comprises four main telescopes called Antu, Yepun, Melipal and Kueyen

Telescope timeline

We reveal how this visual amplification device has evolved century by century

1600s

1608 Dutch perspective glass

He may not have been the first to build one, but German-born spectacle maker Hans Lippershey is credited with designing the first telescope, a refracting one with 3x magnification; it was called the Dutch perspective glass

1610 Galilean telescope

Galileo Galilei perfected Lippershey's design, creating a telescope with a 33x magnification. He used it to make some significant discoveries, like the phases of Venus and some of Jupiter's moons

1668 Newtonian telescope

The first reflecting telescope was honed by Isaac Newton, who created it to help prove his theory that white light actually consists of a spectrum of colours. His telescope used a concave primary mirror and a flat, diagonal secondary mirror

1672 Cassegrain telescope

Priest Laurent Cassegrain came up with a new design for reflecting telescopes, using a concave primary mirror and a convex secondary mirror. This enabled light to bounce through a hole in the primary mirror onto an eyepiece

1700

Maks-Cass telescope up close

The Meade ETX 125 combines quality and portability to make it one of the most popular Maksutov-Cassegrain telescopes around

Lens
The Maksutov-Cassegrain is mainly a reflecting telescope, but has a lens through which light passes before it reaches the mirror to help counteract any aberrations. This corrector lens is a negative meniscus, which has a concave surface on one side and a convex surface on the other

Tube
Maks-Cass scopes have a short tube length relative to the distance that the light actually travels. That's because the mirror setup 'folds' light. Light reflects off the primary mirror at the back of the telescope, which is concave, back to the front. The secondary mirror, which is smaller and convex, reflects the light back through a tiny hole in the primary mirror

Computer controls
Many telescopes can be computer-controlled, which further simplifies locating celestial bodies. You plug in the controller, and you can use it to slew (move) the telescope in any direction. You can also put in your location, and the device will move and locate objects in the sky for quick and easy stargazing

Viewfinder
It can be difficult to locate an object in a telescope, so most come with a viewfinder – a small, wide-field scope that has crosshairs and helps you to centre the telescope on a specific object. This model includes a dew shield

Eyepiece
Light ultimately reaches the back of the telescope, where the eyepiece is located. This telescope uses a Plössl, or symmetrical, eyepiece, which comprises two lenses: one concave and one convex. It makes for a large apparent field of view (the circle of light seen by your eyes)

Setting circles
The declination (on the side) and right ascension (on the bottom) setting circles are used to locate stars and other celestial bodies based on equatorial co-ordinates often found in sky maps. Many telescopes have digital setting circles, which provide the viewer with a database of objects and make it simple to point your telescope in the right direction

Jargon buster

Summing up the basic telescope types

Refractive
Your classic tube telescope, these use a large curved lens at one end, which bends the light that passes through and focuses it at the smaller lens, or eyepiece.

Reflective
These use a concave mirror to send light to a flat mirror. Light is reflected out one side to an eyepiece that magnifies and focuses to create an image.

Compound
Also called catadioptric, these use both lenses and mirrors. They are an all-round telescope for viewing both the planets and deep space.

Solar
These are designed solely to be used during the day to observe the Sun, and often employ a cooling mechanism as the heat can cause turbulence in the telescope.

Astronomical observatory
Land-based ones may contain numerous telescopes, and there are also observatories off our planet, including the Hubble Space Telescope.

1840
First lunar photo
John William Draper was the first to capture the Moon in 1840. Using the daguerreotype process and a 13cm (5in) reflecting telescope, Draper took a 20-minute long exposure and helped found the field of astrophotography

1967
First automated telescope
Arthur Code and other researchers used one of the first minicomputers to control a 20cm (8in) telescope. It measured a fixed sequence of stars using a punched paper tape

1993
Keck telescopes
The Keck telescopes are two 10m (33ft)-diameter reflecting telescopes that saw first light in May 1993. They are located at the WM Keck Observatory on Mauna Kea in Hawaii. Each large mirror is actually composed of smaller segments, which are adjusted and controlled via computers

0s | 1800s | 1900s | 2000s>

1917
Hooker 100-inch telescope
With a 2.5m (8.2ft) reflecting mirror, Hooker's telescope in Los Angeles, CA, was the largest in the world until 1948. Interestingly, in 1924 Edwin Hubble used it to observe galaxies outside the Milky Way, ultimately concluding that our universe is expanding

1990
Hubble Space Telescope
NASA's Discovery shuttle placed the Hubble Space Telescope into low Earth orbit in April 1990. It is a reflecting telescope that contains five different scientific instruments for space observations, including spectrographs and photometers

2005
Large Binocular Telescope
Located in Arizona, the Large Binocular Telescope is one of the most advanced optical telescopes in the world. Built in 2005, it has two 8.4m (28ft) aperture mirrors. The first image observed was of the spiral galaxy NGC 2770, 88 million light years away

The Coronet Cluster as observed by the Chandra X-ray Observatory

© NASA

Telescopes are a wide-ranging form of technology used by scientists, astronomers and civilians alike, to observe remote objects by the collection of electromagnetic radiation

How do telescopes see stars?

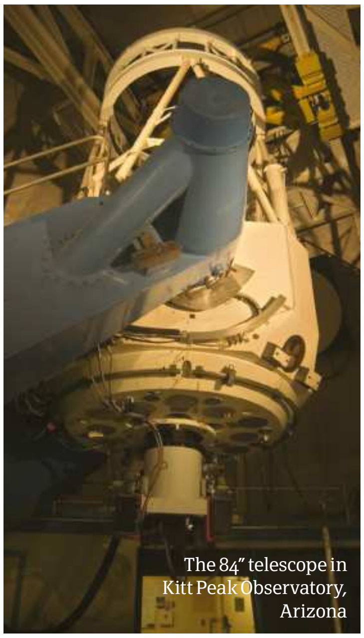
From their origins as simple hand-held instruments formed from a crude coupling of convex objective lens and concave eyepiece used to observe distant objects, to their utilisation in collecting and monitoring electromagnetic radiation emanating from distant space phenomena, telescopes are one of the human race's most groundbreaking inventions. Indeed, now there are telescopes which can monitor, record and image almost all wavelengths of the electromagnetic spectrum, including those with no visible light and their usage is widening our understanding of the world around us and the far-flung reaches of space. Here, we take a look at some of the forms of telescope in use today, exploring how they work and what they are discovering.

Messier 82 is about 12 million light-years away but the Hubble telescope still captured this amazing image

© NASA

NGC 281 is visible in amateur telescopes from dark sky locations

© NASA



The 84" telescope in Kitt Peak Observatory, Arizona

The optical telescope

Since its creation in 1608, the optical telescope has made the close viewing of far away things a piece of cake. But how do they work?

The standard optical telescope works by reflecting or refracting large quantities of light from the visible part of the electromagnetic spectrum to a focus point observable through an eyepiece. In essence, the large objective lens or primary mirror of the telescope collects large quantities of light from whatever it is targeted at, then by focusing that light on a small eyepiece lens, the image formed is magnified across the user's retina, making it appear closer and considerably larger than it actually is. Therefore, the power of any given telescope is directly relative to the diameter or aperture of the objective lens or primary mirror, with the larger the lens/mirror, the further and larger the image produced.

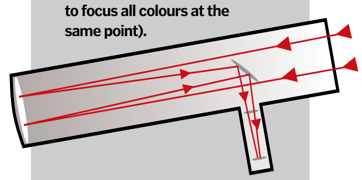
8. Azimuth adjustment knob
A crucial mechanism used to adjust the telescope to the direction of the celestial target

TYPES OF… OPTICAL TELESCOPES

Learn all about the types of optical telescope used by amateur and professional astronomers alike

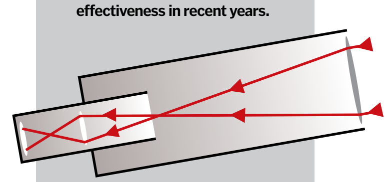
1 Reflecting

One of the most common types of optical telescope, a reflector utilises one curved mirror and one flat mirror to directly reflect light throughout its main body and form an image. The reflecting telescope was created in the 17th Century as an alternative to the refracting telescope, which at the time suffered from severe chromatic aberration (a failure to focus all colours at the same point).



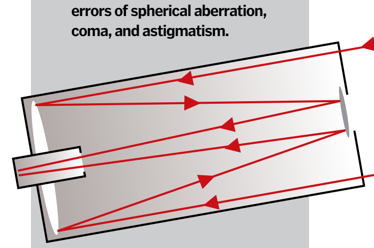
2 Refracting

The first type of telescope to be invented in 1608 was a refractor. Utilising a partnership of a convex objective lens and a concave eyepiece lens to form its image, refractors are still used today. However, there are numerous technical considerations including lens sagging, chromatic aberration and spherical aberration that have demeaned their effectiveness in recent years.



3 Catadioptric

The most advanced and stable of all optical telescopes are catadioptrics, which employ a mixture of mirrors and lenses to form an image, as well as a number of correctors to maintain accuracy. The first catadioptric telescope was made by the optician Bernhard Schmidt who, with his patented Schmidt telescope, corrected the optical errors of spherical aberration, coma, and astigmatism.



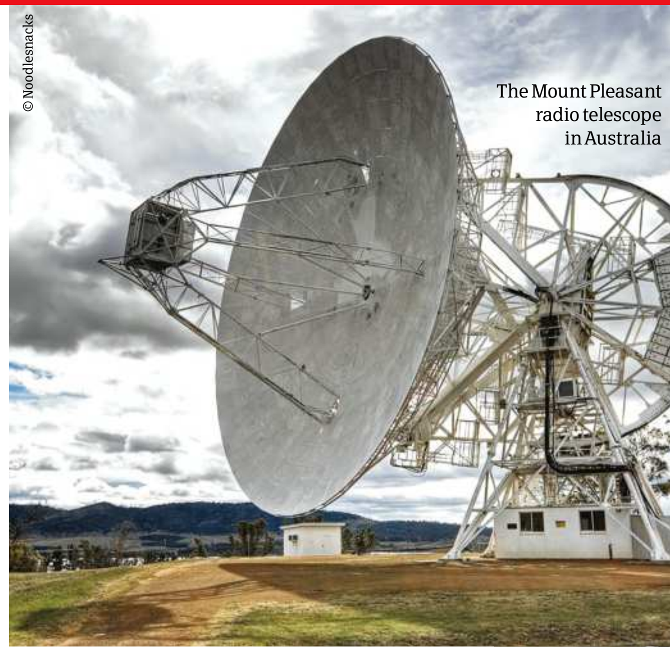
Radio telescopes

Characterised usually by their large dishes, radio telescopes allow us to receive signals from the depths of space

The radio telescope works by receiving and then amplifying radio signals produced from the naturally occurring emissions of distant stars, galaxies and quasars. The two basic components of a radio telescope are a large radio antenna and a sensitive radiometer, which between them reflect, direct and amplify incoming radio signals typically between wavelengths of ten metres and one millimetre to produce comprehensible information at an optical wavelength. Due to the weak power of these cosmic radio signals, as well as the range in wavelength that they operate in, radio telescopes need to be very large in construction, as the efficiency of the antenna is crucial and can easily be distorted by potential terrestrial radio interference.

The most common radio telescope seen is the radio reflector; this consists of a parabolic antenna – the large visible dish – and operates in a similar manner to a television satellite dish, focusing incoming radiation onto a receiver for decoding. In this type of radio telescope, often the radio receiver/solid-state amplifiers are cryogenically cooled to reduce noise and interference, as well as having the parabolic surface of the telescope equatorially mounted, with one axis parallel to the rotation axis of Earth. This equatorial mounting allows the telescope to follow a fixed position in the sky as the Earth rotates, therefore allowing elongated periods of static, pinpoint observation.

The largest filled-aperture telescope is the Arecibo radio telescope located in Puerto Rico, which boasts a 305-metre dish. Contrary to other radio telescopes with movable dishes however, the Arecibo's dish is fixed, instead relying on a movable antenna beam to alter its focus.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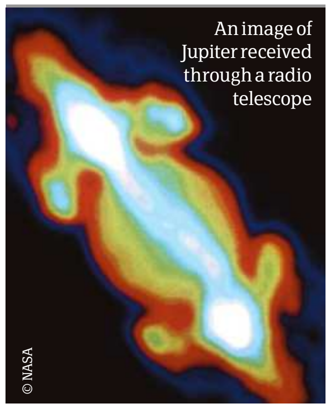
The Mount Pleasant radio telescope in Australia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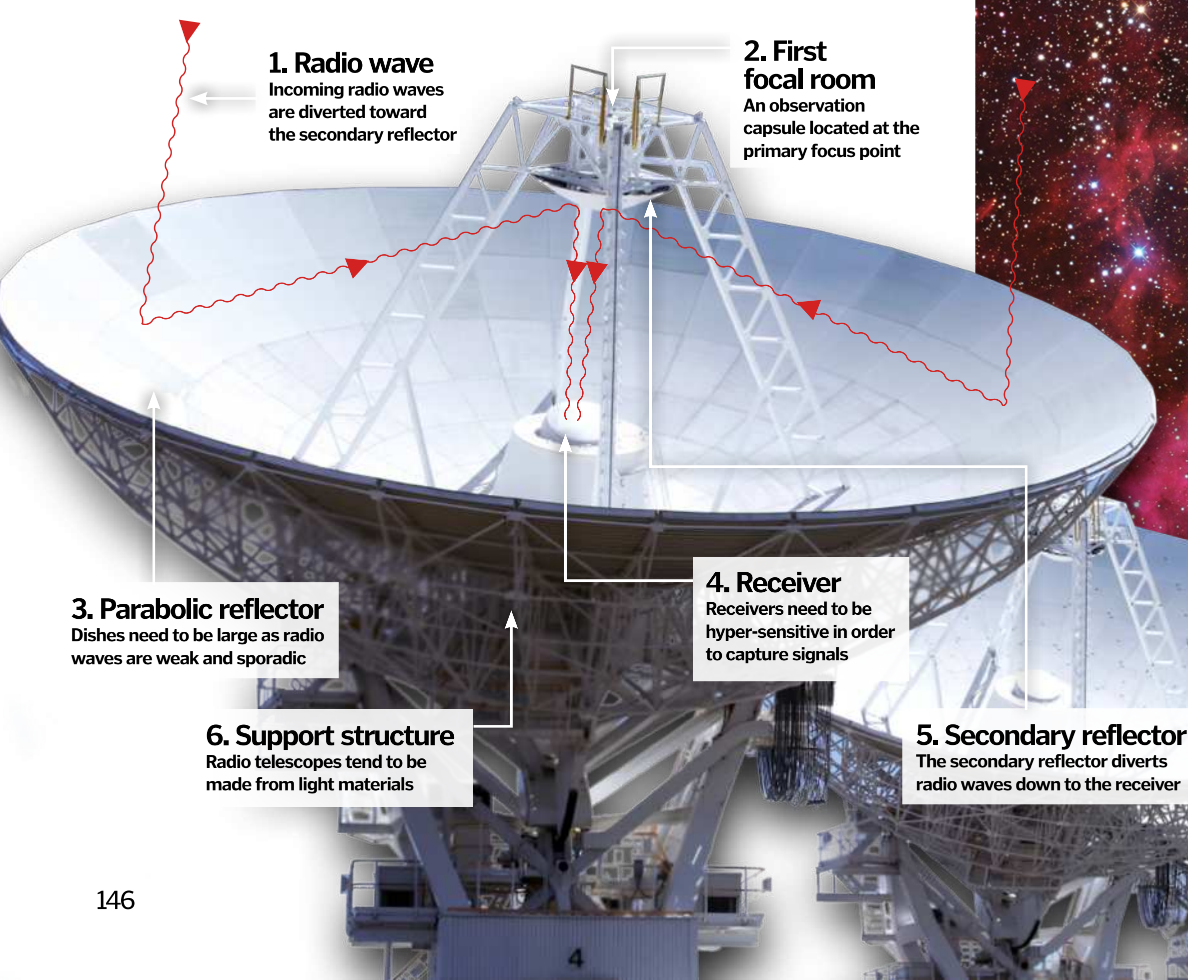
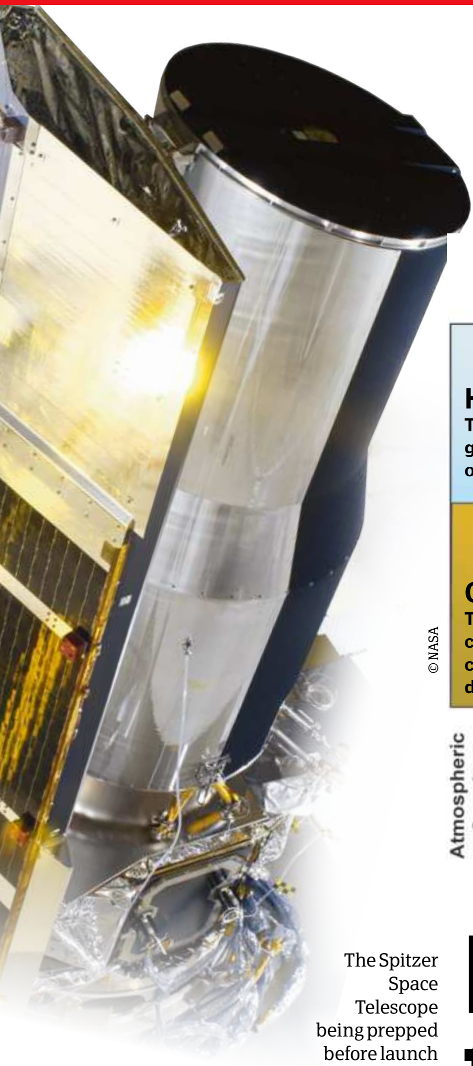
An image of Jupiter received through a radio telescope


© NASA

A supernova remnant imaged from signals received by a radio telescope





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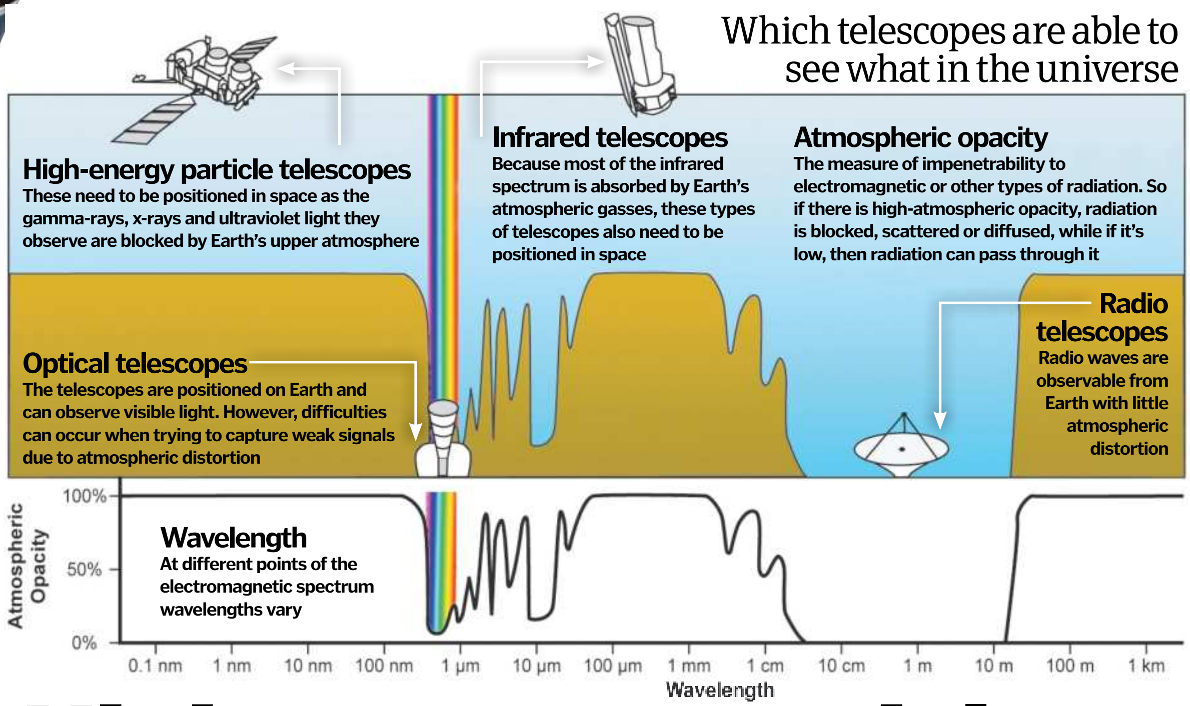
The Spitzer Space Telescope being prepped before launch

Telescope classification

Which telescopes are able to see what in the universe



High-energy particle telescopes

Advanced technology is pushing back the boundaries of high-energy astronomy

The limits of radio and optical telescopes have led scientists in exciting new directions in order to capture and decode natural signals from distant galaxies.

One of the most notable is the x-ray telescope, which differs in its construction thanks to the inability of mirrors to reflect x-ray radiation, a fundamental necessity in all reflection-based optical and radio telescopes. In order to capture x-ray radiation, instead of being directly reflected into a hyper-sensitive receiver for amplification and decoding, it is acutely reflected a number of times, changing the course of the ray incrementally each time. To do this the x-ray telescope must be built from several nested cylinders with a parabolic or hyperbolic profile, guiding incoming rays into the receiver.

Crucially, however, all x-ray telescopes must be operated outside of the Earth's atmosphere as it is opaque to x-rays, meaning they must be mounted to high-altitude rockets or artificial satellites. Good examples of orbiting x-ray telescopes can be seen on the Chandra X-ray Observatory and the Spitzer Space Telescope.

Other high-energy particle telescopes include gamma-ray telescopes, which study the cosmos through the gamma-rays emitted by stellar processes, and neutrino telescopes, a form of astronomy still very much in its infancy. A neutrino telescope works by detecting the electromagnetic radiation formed as incoming neutrinos create an electron or muon (unstable sub-atomic particle) when coming into contact with water.

Because of this, neutrino telescopes tend to consist of submerged phototubes (a gas-filled tube especially sensitive to ultraviolet and electromagnetic light) in large underground chambers to reduce interference from cosmic rays. The phototubes act as a recording mechanism, storing any Cherenkov light (a type of electromagnetic radiation) emitted from the interaction of the neutrino with the electrons or nuclei of water. Then, using a mixture of timing and charge information from each of the phototubes, the interaction vertex, ring detection and type of neutrino can be detected.

The Rosette Nebula

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The Chandra X-ray Observatory

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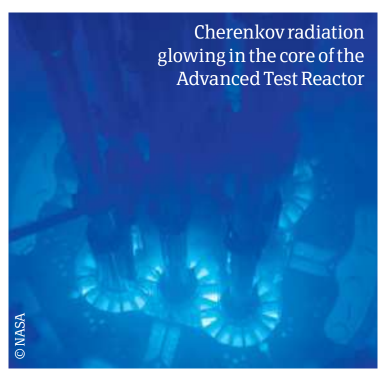


Cherenkov radiation glowing in the core of the Advanced Test Reactor

© NASA

James Webb Space Telescope

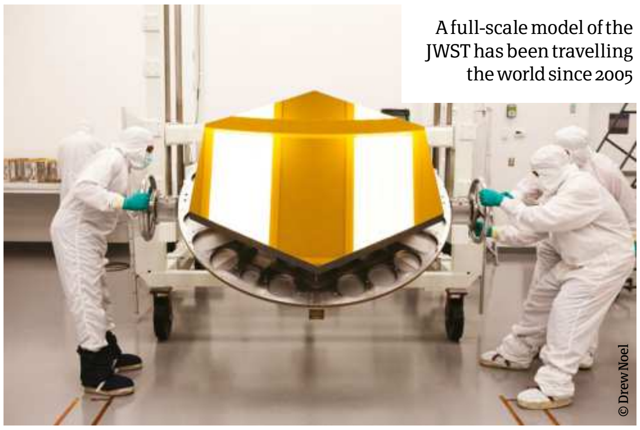
The successor to Hubble will change the way that we see the universe

The James Webb Space Telescope (JWST), originally known as the Next Generation Space Telescope, employs engineering techniques never used on a space telescope before and will produce unparalleled views of the universe. Originally scheduled to launch in 2018, delays mean the JWST is scheduled for launch in 2021 in a joint venture between the ESA, NASA and the Canadian Space Agency. Primarily, the JWST will observe infrared light from distant objects.

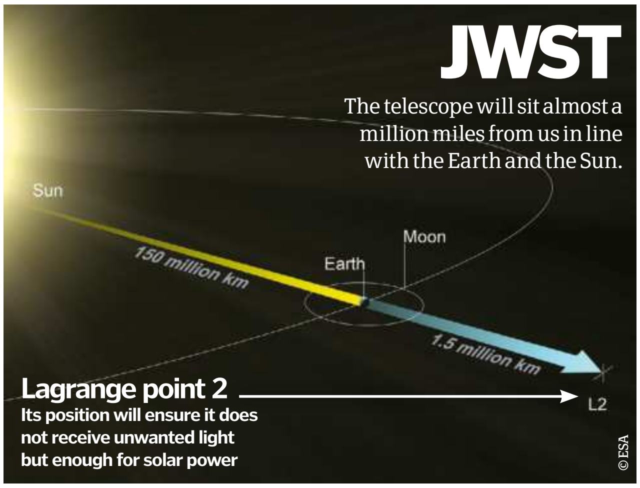
To gather light on the telescope the primary mirror on the JWST is made of 18 hexagonal beryllium segments, which are much lighter than traditional glass and also very strong. To roughly point the telescope in the direction of its observations a star tracker is used, and a Fine Guidance Sensor (FGS) is employed to fine-tune the viewings.

The secondary mirror on the JWST, which reflects the light from the primary mirror into the instruments on board, can be moved to focus the telescope on an object. Each of the 18 hexagonal segments can also be individually adjusted and aligned to produce the perfect picture. While Hubble's primary mirror is just 2.4 metres in diameter, the mirror on JWST is almost three times as big at 6.5 metres in diameter, allowing for much more distant and accurate observations.

A box called the Integrated Science Instrument Module (ISIM) sits behind the primary mirror to collect the light incident on the telescope. The ISIM is attached to a backplane, which also holds the telescope's mirrors and keeps them stable. A sunshield, composed of five layers of Kapton with aluminium and special silicon coatings to reflect sunlight, protects the incredibly sensitive instruments.



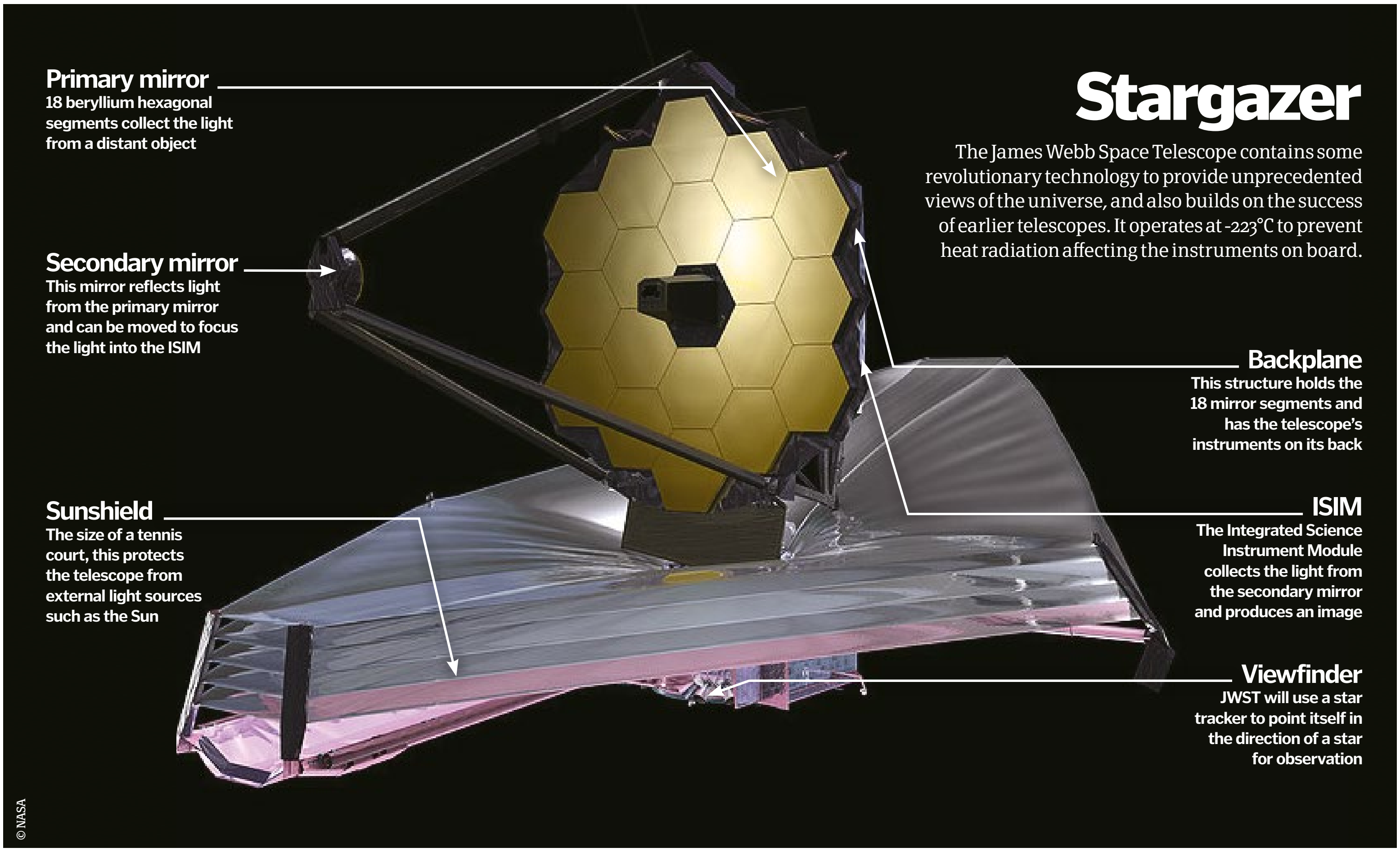
A full-scale model of the JWST has been travelling the world since 2005



JWST

The telescope will sit almost a million miles from us in line with the Earth and the Sun.

Lagrange point 2
Its position will ensure it does not receive unwanted light but enough for solar power



Stargazer

The James Webb Space Telescope contains some revolutionary technology to provide unprecedented views of the universe, and also builds on the success of earlier telescopes. It operates at -223°C to prevent heat radiation affecting the instruments on board.

Primary mirror
18 beryllium hexagonal segments collect the light from a distant object

Secondary mirror
This mirror reflects light from the primary mirror and can be moved to focus the light into the ISIM

Sunshield
The size of a tennis court, this protects the telescope from external light sources such as the Sun

Backplane
This structure holds the 18 mirror segments and has the telescope's instruments on its back

ISIM
The Integrated Science Instrument Module collects the light from the secondary mirror and produces an image

Viewfinder
JWST will use a star tracker to point itself in the direction of a star for observation

European Extremely Large Telescope

How will this record-breaking observatory hunt for Earth-like planets?

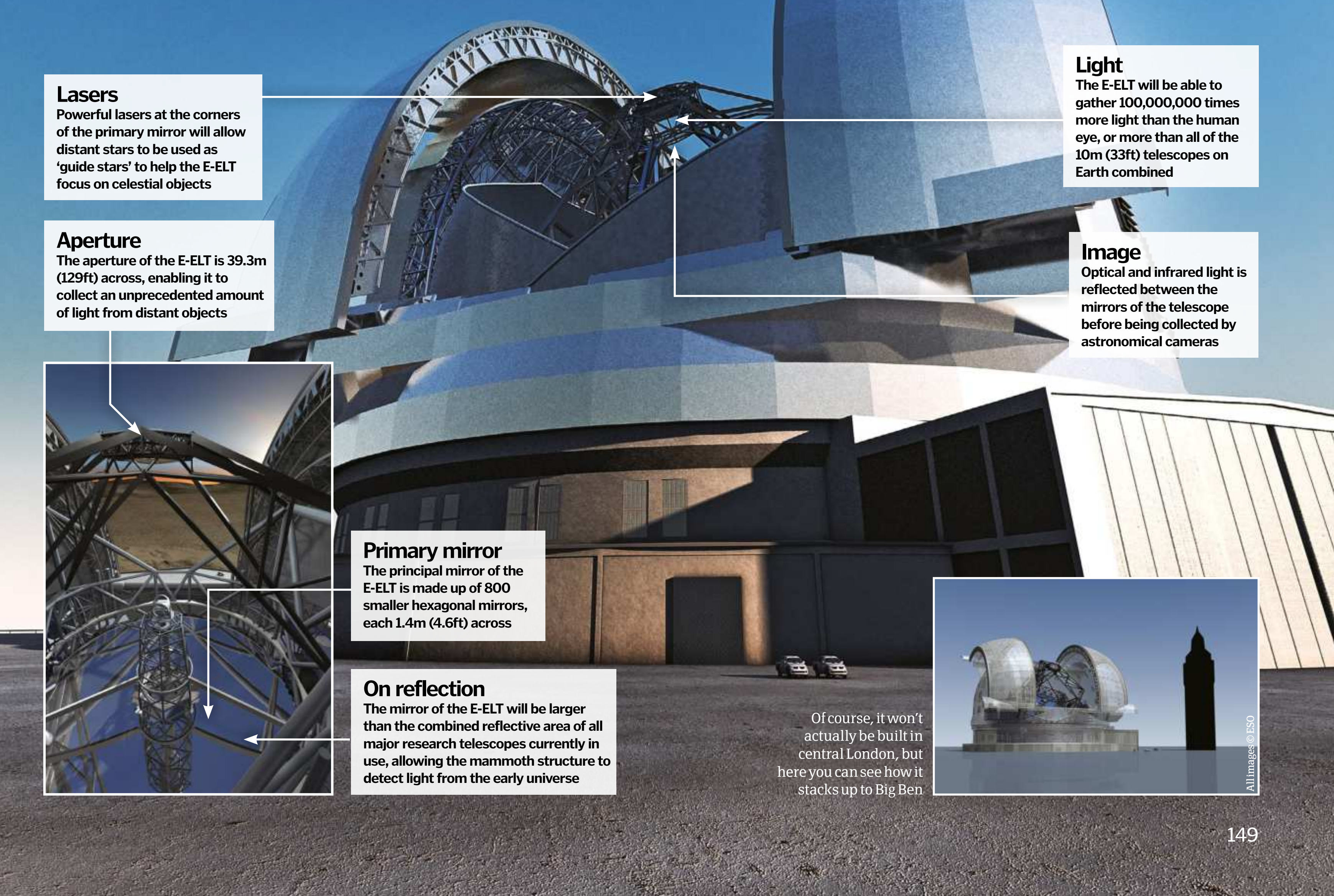
Since its invention over 400 years ago the humble telescope has come on leaps and bounds. In the early 20th Century astronomers relied on old single or twin-mirror methods to produce images of distant galaxies and stars, but as the size of telescopes increased the quality of imagery reduced. It wasn't until the arrival of the Keck Observatories in Hawaii in the Eighties and Nineties, using 36 smaller mirror segments stitched together like a honeycomb, that telescopes were really able to view distant corners of the universe in stunning detail. This segmented design provides the basis for how the next generation of super-powerful telescopes will work, such as the European Extremely Large Telescope (E-ELT), which is being built by the European Southern Observatory.

What makes the E-ELT stand out from the crowd is its sheer size. Currently, the largest telescope in operation on Earth is the Large Binocular Telescope in Arizona, USA, sporting an aperture that measures a 'measly' 11.9 metres (39 feet) in diameter. The aperture of the E-ELT comes in at a mammoth 39.3 metres (129 feet), about half the size of a football pitch.

The telescope, expected to be finished within a decade, will be built on Cerro Armazones, a 3,000-metre (9,800-foot) mountain located in Chile's Atacama Desert where many other telescopes, including the recently activated Atacama Large Millimeter/submillimeter Array (ALMA), reside. The benefit of this location is obviously its altitude, allowing the cosmos to be viewed with less atmospheric interference than would be experienced at sea level, although some will still be present.

To overcome remaining atmospheric interference, the E-ELT will use a technology known as adaptive optics. Disturbances in the atmosphere can be accounted for by measuring the air that is within the telescope's view. Tiny magnets move its 800 segmented mirrors about 2,000 times a second to adjust the view to avoid any turbulence.

The primary goal of the E-ELT is to observe Earth-like planets in greater detail than ever before, but it will also be able to see much fainter objects – possibly even the primordial stars that formed soon after the Big Bang. Apart from the E-ELT there are two other extremely large telescopes under construction: the 24.5-metre (80-foot) Giant Magellan Telescope and the Thirty Meter Telescope (which will be 98 feet); both are also expected to be completed within a decade.



Of course, it won't actually be built in central London, but here you can see how it stacks up to Big Ben

How far can we see into space?

Find out how astronomers calculate the distances to far-away galaxies

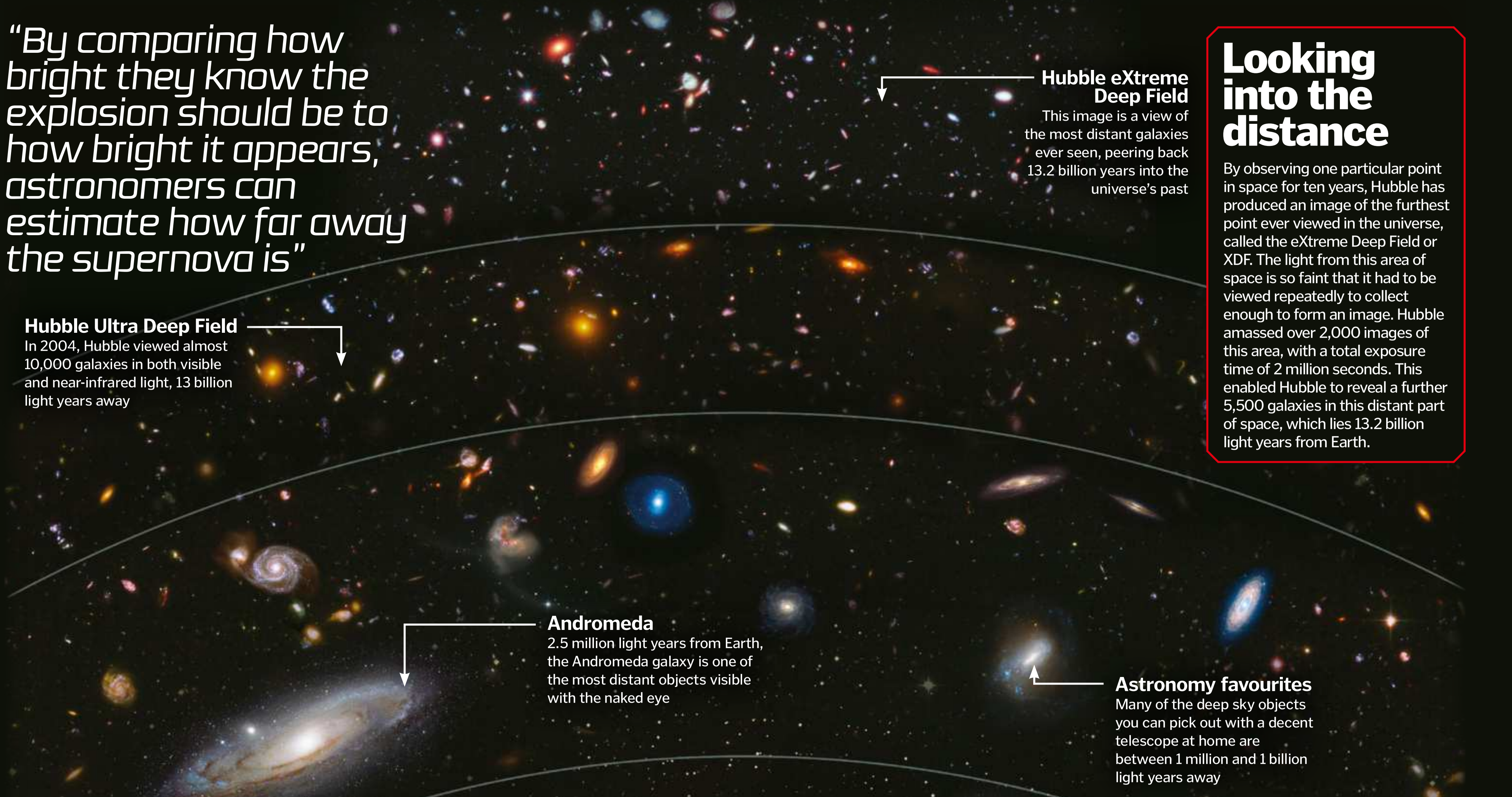
Using the naked eye, it's possible to spot the Andromeda galaxy. It has been visible to mankind long before we even knew it was another galaxy, but scientists are now determined to explore beyond the realms of nearby galaxies into the vast expanse of the universe.

During its 25 years of service, the Hubble Space Telescope has provided an incredible amount of data, helping astronomers see further than ever before. Among its most famous contributions are the Hubble Deep Field images, which have provided us with the most detailed glimpses into the farthest reaches of the visible universe.

Calculating just how far away Hubble's most distant discoveries are from Earth is challenging, but astronomers have found a way to do this accurately. They measure the brightness of Type Ia supernovas – where a white dwarf feeds on its binary partner star until it detonates. As astronomers know these stars always explode when they reach a specific mass (1.4 times that of our Sun), the resultant supernova should always be a particular brightness. By comparing how bright they know the explosion should be to how bright it appears to be, astronomers can estimate how far away the supernova (and therefore its parent galaxy) is from us.

This system works well for galaxies up to around 3 billion light years away, but for anything further, astronomers use the Hubble Constant. Edwin Hubble discovered that the universe is constantly expanding in all directions, which means the further away you look, the faster the galaxies are moving away from Earth. This produces a phenomenon known as redshift, whereby light shifts to the red end of the spectrum as its wavelength is stretched. By measuring redshift, you can estimate how fast an object is moving, and thus its approximate distance from Earth. Thanks to this clever piece of physics, astronomers can calculate reasonable estimates to the outer reaches of the observable universe. For example, the galaxies in Hubble's farthest Deep Field image, called the 'eXtreme Deep Field', are around 13.2 billion light years away.

"By comparing how bright they know the explosion should be to how bright it appears, astronomers can estimate how far away the supernova is"



Hubble Ultra Deep Field
In 2004, Hubble viewed almost 10,000 galaxies in both visible and near-infrared light, 13 billion light years away

Hubble eXtreme Deep Field
This image is a view of the most distant galaxies ever seen, peering back 13.2 billion years into the universe's past

Andromeda
2.5 million light years from Earth, the Andromeda galaxy is one of the most distant objects visible with the naked eye

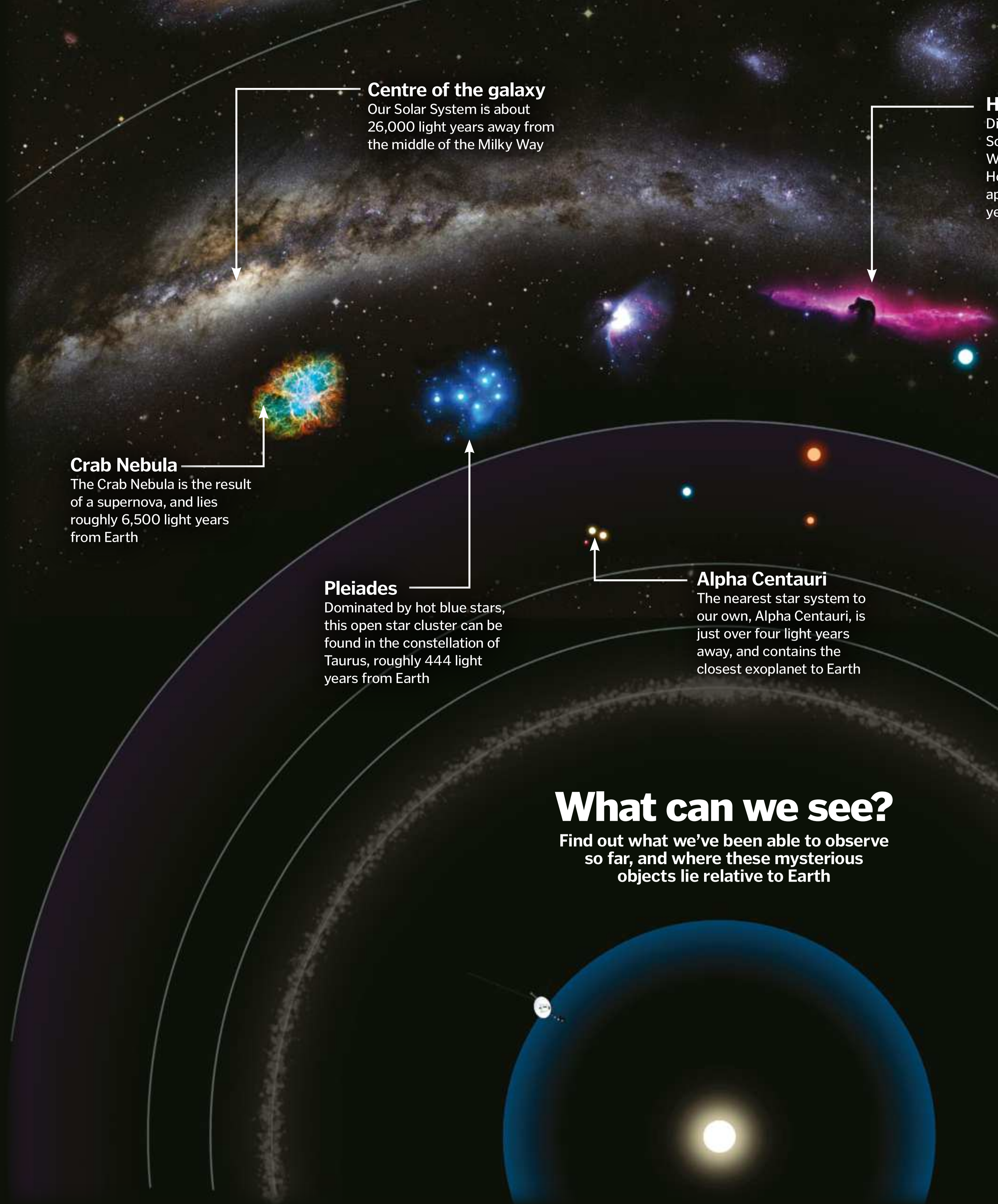
Astronomy favourites
Many of the deep sky objects you can pick out with a decent telescope at home are between 1 million and 1 billion light years away

Looking into the distance

By observing one particular point in space for ten years, Hubble has produced an image of the furthest point ever viewed in the universe, called the eXtreme Deep Field or XDF. The light from this area of space is so faint that it had to be viewed repeatedly to collect enough to form an image. Hubble amassed over 2,000 images of this area, with a total exposure time of 2 million seconds. This enabled Hubble to reveal a further 5,500 galaxies in this distant part of space, which lies 13.2 billion light years from Earth.

What can we see?

Find out what we've been able to observe so far, and where these mysterious objects lie relative to Earth



The James Webb Space Telescope

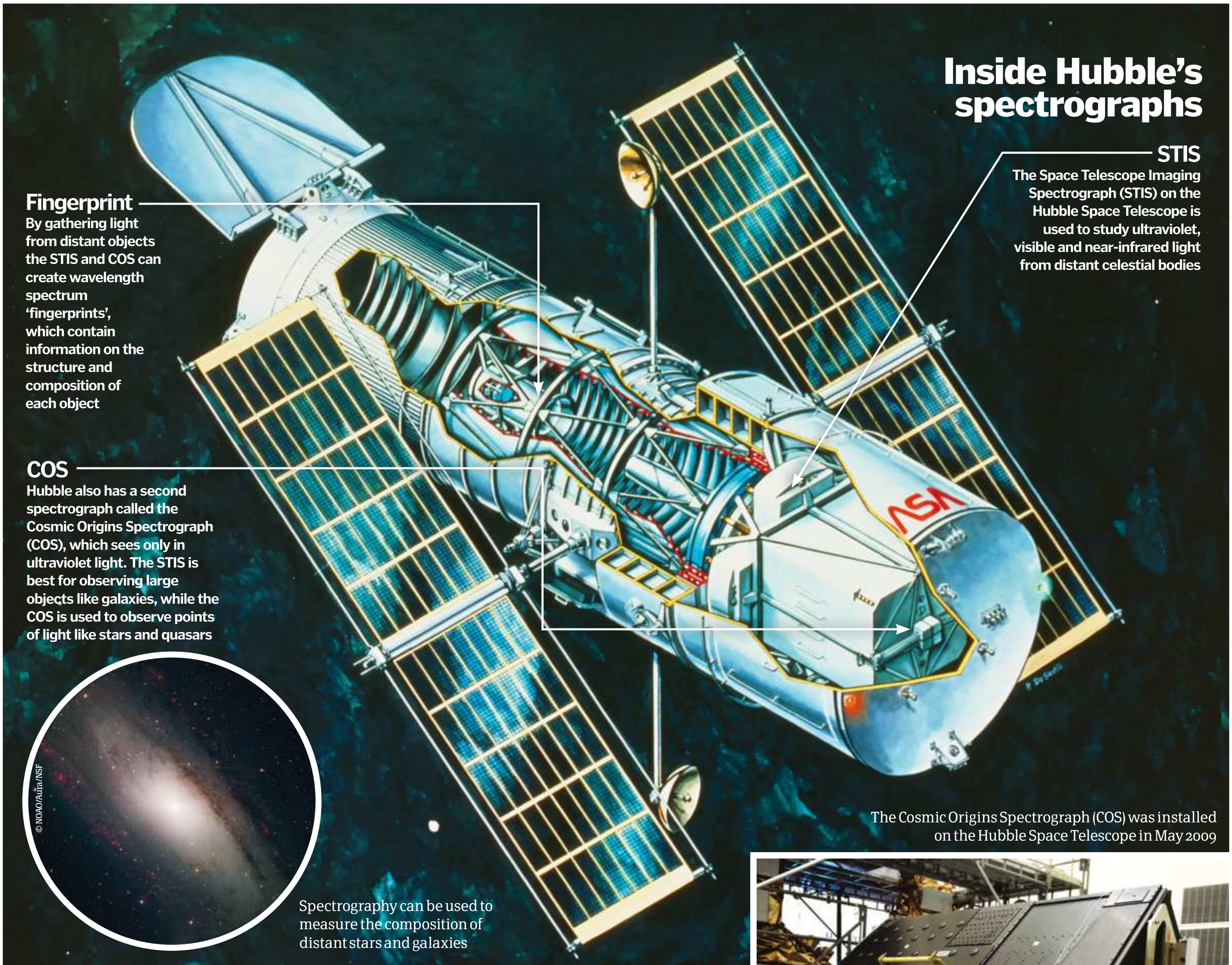
When the James Webb Space Telescope (JWST) launches in October 2018, it will be tasked with studying each phase in the history of the universe, aiming to find the first galaxies to form after the Big Bang and determine how they came to exist.

The JWST's most striking feature is a layered sunshield that will work to reduce the Sun's heat in order to protect the instruments on board. This tennis court-sized sunshield splits the telescope into two sections. The warm side is equipped with solar panels, communication devices, and steering, while the cold side houses the telescope itself and other scientific instruments, which all need to operate at temperatures below -223 degrees Celsius (-370 degrees Fahrenheit).

This is because the JWST will be trying to observe faint infrared light from exceptionally far away objects in the eXtreme Deep Field, and must avoid swamping the sensitive instruments with excess infrared radiation from the Sun.

If all goes to plan, the JWST will detect the faint light from these distant targets, allowing us to see even further than Hubble, to when the universe was in its infancy 13.5 billion years ago.


The JWST is designed to examine the early universe in more detail



Spectrography can be used to measure the composition of distant stars and galaxies

The Cosmic Origins Spectrograph (COS) was installed on the Hubble Space Telescope in May 2009

Spectrography

How can we determine the composition of a distant star?

Spectrography, or spectroscopy, is the study of light from distant objects (such as a black hole or galaxy) to analyse their composition, movements and structure.

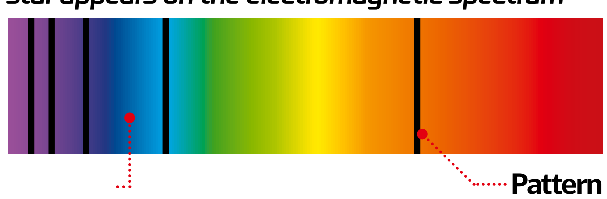
It works by measuring the intensity of light present across a range of energies on the electromagnetic spectrum. Every element in the universe has a particular pattern of black lines, known as emission lines, unique to that element on the spectrum. By matching the known emission lines of an element to those observed on a spectrum from an object, the composition can be determined.

A spectrometer is an instrument that is used to analyse these electromagnetic spectrums. In practice, it does this by observing the light (be it visible, infrared or otherwise) emitted from a source, and deducing the various energies associated with that light. Depending on the elements that are present in a celestial body, the spectrum it produces will be different to that from any other body.

Spectrometers are used on a variety of space telescopes, including the Hubble Space Telescope (see the above diagram), but they can also be used here on Earth to study not only distant space phenomena but objects on our planet too, like plants and minerals. Spectrography is very useful in astronomy, providing us with the answers to how stars form, what they are made of and more.

Hydrogen spectrograph

Discover how the emission of hydrogen from a star appears on the electromagnetic spectrum



Pattern
By matching the pattern of lines with existing spectrographs, scientists can establish what they are looking at

The Leonids

While not the most consistent of meteor showers, the Leonids can be one of the most dynamic spectacles in an astronomer's calendar. They're a product of the comet Tempel-Tuttle, which has a radius of around 1.8 kilometres (1.1 miles) and has a 33-year cycle. The comet itself is fairly unremarkable compared to the likes of Halley's or Hale-Bopp, however it leaves behind a dense stream of debris that results in a meteor shower rate that can reach as many as 300 meteors an hour.

© NASA

Meteor showers

Why the most famous of these celestial spectacles are an annual event

Meteors enter the Earth's atmosphere all the time. Spend a little time looking up at the sky at night in the country or a place with similarly low light pollution and there's a good chance you'll see a 'shooting star', the result of air friction burning the meteor up. At certain times of the year astronomers can even forecast an increase in their frequency and luminosity as annual meteor showers hit our planet. So why do these occur regularly and how are scientists able to predict them?

A meteor shower is a group of meteors that originate from the same source. In the common case of one of the most prolific annual meteor shower events in the cosmic calendar, the Perseids, they're material stripped off the comet Swift-Tuttle by solar radiation as it passes the Sun. This debris then trails behind the comet, spreading out along its orbit and, if the Earth's own orbit crosses its path, then a meteor shower ensues. As it happens, both Earth and Swift-Tuttle follow very regular paths, which is why when Earth crosses Swift-Tuttle's orbit a predictable, late-July event occurs that peaks in August at around 75 meteors an hour.

Perhaps the most famous comet of them all, Halley's, has its own regular meteor shower called the Orionids that appear in October, though at a much lower rate than the Perseids.

Is the Swift-Tuttle comet a threat?

Swift-Tuttle has a 130-year orbit of the Sun and its first recorded sighting was by astronomers Lewis Swift and Horace Tuttle over a century ago in July 1862. Astrophysicist Brian Marsden's calculations for the next perihelion (the name for any satellite's closest approach to the Sun) in 1992 were off by 17 days, which put the comet on a potential collision course with Earth in 2126. It panicked astronomers, as the comet is around 9.7 kilometres (six miles) wide, which is roughly the same size as the Chicxulub asteroid that's held to be the major culprit in the extinction of the dinosaurs 65 million years ago. But having traced Swift-Tuttle's orbit back 2,000 years, Marsden was able to refine his calculations to put the comet a comfortable 24 million kilometres (15 million miles) away for its next appearance. However, if the calculations play out, there *will* be a real cosmic near-miss when 3044 rolls around, as Swift-Tuttle will pass within just 1.6 million kilometres (1 million miles) of our planet.

© SPL

Wildest weather in space

We complain about Earth's weather, but the weather in space is on another scale

Weather on Earth can be extreme, but whatever's happening outside right now where you are, it's a safe bet that it's better than the weather in the rest of the Solar System.

Earth has the nicest weather thanks to a number of features: its size, its distance from the Sun, its axial tilt, orbital and rotational period, and its chemical composition. Although Earth's meteorology can be devastating, in comparison to some of our planetary neighbours, it's actually rather mild. Plus, a lot of our weather can be summed up in one word: water (albeit in various forms). Meanwhile, on planets lacking water, an atmosphere or a magnetic field to shield them from the worst of the Sun's radiation, you have to wonder why we're so keen to visit any of them!

One factor all of the planets have in common is the Sun and its emissions. The heliosphere is considered a part of the Sun's atmosphere, but it extends beyond Pluto, about 19 billion kilometres (12 billion miles) from the star. So Earth does have some weather in common with other planets. In February 2014, researchers at NASA's Goddard Space Flight Center discovered a phenomenon that is common and rather pedestrian on Earth has much greater repercussions on Venus. A type of solar wind called a hot flow anomaly (HFA) causes massive explosions of energy, but on Earth it's deflected by the magnetosphere. However, Venus has no magnetosphere, so the explosions can cover the entire planet. Not that it was particularly hospitable anyway.

That's not even the strangest weather in the Solar System. While studying it can be hard, our history of flybys, missions and probes help us to create detailed models of climate on other planets like Mars. Learning about similar effects on other planets is helping us to predict and prepare for changes in weather on Earth.

Jupiter's Great Red Spot

One of the defining features of the Solar System's biggest planet is a storm located about 22 degrees south of the equator in the South Equatorial Belt (SEB), commonly known as the Great Red Spot (GRS). Astoundingly, the GRS has been raging for more than 400 years, and is located at a higher altitude and measures colder than the surrounding cloud layer. It rotates anticlockwise, making one full rotation every six Earth days and is currently as large as two Earths across. The storm has shrunk by half its size in the past 100 years – at one point its diameter was measured at more than 40,000 kilometres (24,855 miles).

The GRS is different from storms on Earth because the heat generated within the planet continually replenishes it. Hurricanes on Earth dissipate when they make landfall, but Jupiter is gaseous, so the storm rages on. Jupiter's atmosphere is composed of cloud belts that rotate due to a system of jet streams. The northern side of the storm is bordered by an eastward jet stream and the southern side by a westward jet stream. These hold the storm in place as it makes laps around the planet.

Despite the high winds around it, there's little wind inside the storm. Its colour is probably caused by sulphuric compounds and varies from white to dark red, and sometimes it isn't visible at all. These colour changes seem to correspond to colour changes in the SEB, but without any predictable schedule.

Has lasted over 4,700x longer than Earth's longest storm

Dust storms can drastically raise the temperature, as the particles trap heat in Mars's atmosphere

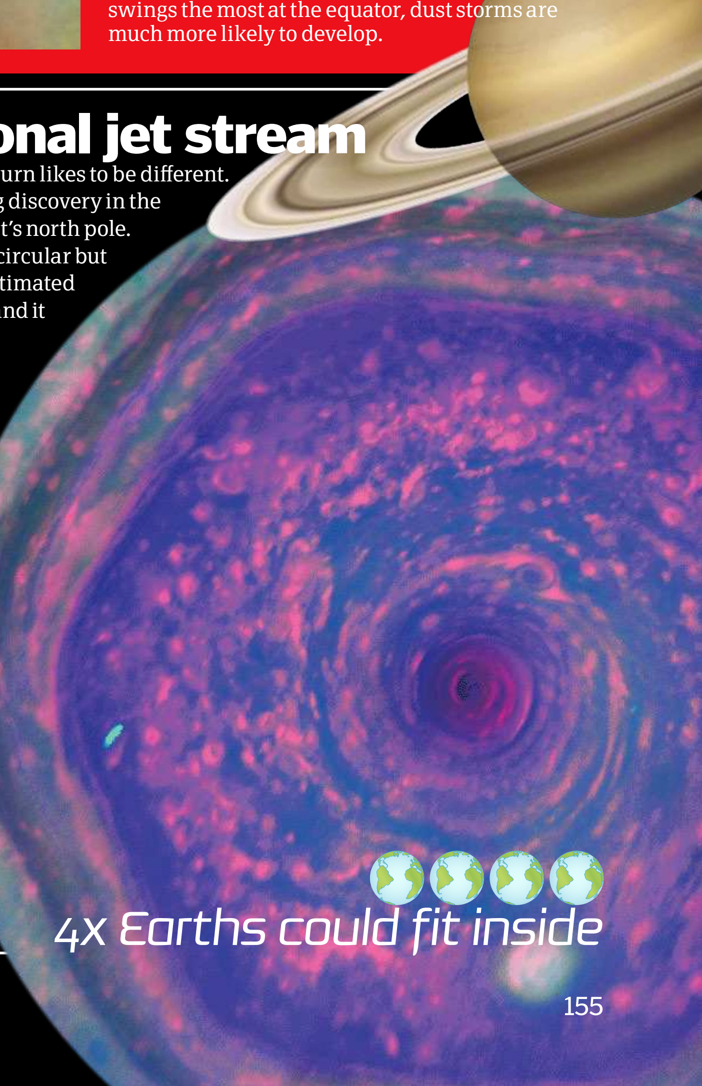
Dust storms on Mars

Earth's deserts have nothing on the Martian landscape when it comes to dust storms. The Red Planet is so dry, dusty and rocky that its dust storms can last for weeks. These storms develop quickly and can cover vast regions of the planet. Because the Martian atmosphere is so thin, superfine particles of dust rise in the air as heat from the Sun warms up the atmosphere.

Mars has such an eccentric orbit compared to Earth, that its seasons are very extreme; temperatures can be as low as -143 degrees Celsius (-225.4 degrees Fahrenheit) and as high as 35 degrees Celsius (95 degrees Fahrenheit). During Martian summers, when the temperature swings the most at the equator, dust storms are much more likely to develop.

Saturn's hexagonal jet stream

Jet streams are generally circular, but Saturn likes to be different. The Voyager mission made an interesting discovery in the early-Eighties when flying over the planet's north pole. It's surrounded by a jet stream that's not circular but hexagonal. Each side of the hexagon is estimated to be 15,000 kilometres (9,321 miles) long and it has a 30,000-kilometre (18,640-mile) diameter. It surrounds a vortex and rotates at the same rate as Saturn (a day on Saturn is about ten and a half hours). University of Oxford physicists re-created the process in a lab using a cylinder of water as the planet's atmosphere with a ring inside it representing the jet stream. The cylinder was placed on a spinning table and the ring spun faster than the water. The faster the spin, the less circular the jet stream became. By varying the speed and the differences between rotations of the water and the ring, different shapes appeared. The theory is that the rate at which this particular jet stream spins in relation to Saturn's atmosphere creates the hexagonal formation.



4x Earths could fit inside

What role does the Sun play in space weather?

There are numerous factors that affect weather on each planet in the Solar System, but they all have one thing in common: the Sun. Two main types of solar activity take place in the Sun's atmosphere that have far-reaching effects. Coronal mass ejections (CMEs) and solar flares can wreak havoc on a planet. CMEs are bursts of magnetic fields and solar winds that release matter and electromagnetic radiation. Solar flares are massive bursts of light and energy that release atoms, ions, electrons and radiation. A CME usually follows a solar flare.

These energy surges from the Sun can result in solar energetic particles (SEPs), highly energised particles including electrons, ions and protons that can travel as fast as 80 per cent the speed of light. SEPs and other matter and radiation that reach Earth cause geomagnetic storms that can have a variety of effects. They cause the stunning polar auroras, but other effects are less desirable.

In the case of solar flares, there's an increase in the amount of UV radiation in the Earth's atmosphere, which can affect the movement and longevity of satellites by making the atmosphere denser. They can cause interference and disruption of communications and navigation on the surface, while particles from flares can damage the delicate electronics found on satellites or the International Space Station. They can even cause changes in the Earth's climate.

Saturn's diamond rain

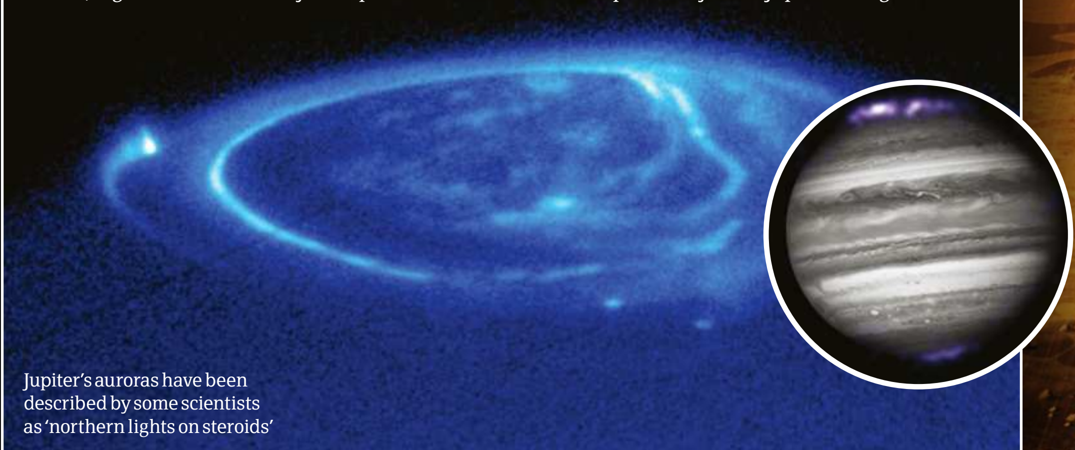
Some researchers believe that lightning storms on Saturn may result in diamond precipitation – as much as 1,000 tons each year. The theory is that lightning zapping the methane in the atmosphere releases carbon atoms from the gas. These carbon atoms stick together and drift down towards the planet's core. As the pressure and temperature mount, the carbon is compressed into graphite and eventually diamonds that could be as big as a centimetre (0.4 inches) in diameter. However, when diamonds reach the core – where temperatures can be as hot as 7,727 degrees Celsius (13,940 degrees Fahrenheit) – the gems would melt.

Violent Neptunian winds

The outermost planet in our Solar System has some seriously extreme weather in general, but what really blows astronomers away is its wind. In fact, Neptune is home to the strongest gales anywhere in the Solar System, topping out at over 2,100 kilometres (1,300 miles) per hour – about the speed of a fighter jet. By comparison, winds on Earth generally max out at 400 kilometres (250 miles) per hour. These powerful winds move in the opposite direction to the rotation of the planet, and there are two different theories for what causes them. One idea is that although they're powerful, these winds remain high in the atmosphere, in a layer no more than 1,000 kilometres (600 miles) thick. This means that the processes causing these winds are also shallow, likely due to the condensation and evaporation of moisture in the atmosphere. The other theory is that these processes are much lower in the atmosphere, caused by the meeting of the heat generated from within the planet as its core shrinks as it meets the extreme cold at the surface (below -200 degrees Celsius/-328 degrees Fahrenheit). If the winds do prevail deeper into the atmosphere, they may also be intense because the planet's surface contains nothing to slow them.

Jupiter's electric auroras

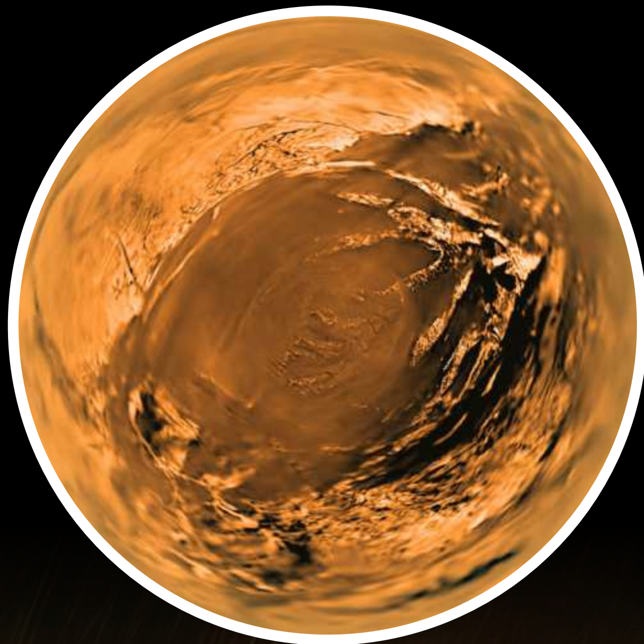
The auroras on Earth get a lot of attention for their beauty, but Jupiter has auroras larger than the entire Earth. In fact, they produce nearly a million megawatts of energy! And unlike Earth-based auroras, they're always happening. On Earth, the light displays are caused by solar storms, but Jupiter's auroras are self-generated. As the planet rotates, it generates electricity at its poles and forces charged particles (ions) into the atmosphere, causing a reaction resulting in beautiful displays. One potential source of the ions is Jupiter's moon Io, but scientists aren't sure how this happens. Ultraviolet images of the auroras reveal their blue glow, and three blobs of light. These are Galilean moons Io, Ganymede and Europa as they meet Jupiter's magnetic field.



Jupiter's auroras have been described by some scientists as 'northern lights on steroids'

Titan is home to methane rain

Titan looks Earth-like thanks to its abundance of lakes, rivers and clouds. But appearances can be deceiving; instead of a water cycle, Saturn's largest satellite has a methane cycle. Seasonal rains fill the moon's basins, the contents of which evaporate and condense into clouds that once again release rain.



Titan's methane cycle in focus

Titan has a methane/ethane cycle that follows the seasons, similar to the monsoon rains in some places on Earth

Top five weather satellites

GPM – Launch: 2014

The Global Precipitation Measurement is designed to provide 4D views of hurricanes, rainstorms and even falling snow on Earth. It provides both long-term climate research and live weather forecasts.

DSCOVR – Launch: 2015

The Deep Space Climate Observatory satellite will spot space weather (like solar flares) that could be damaging to Earth. DSCOVR is in an orbit 1.5mn km (932,000mi) away to escape some of the Earth's magnetic effects.

SOHO – Launch: 1995

The Solar and Heliospheric Observatory mission is in a halo orbit around the Earth. SOHO was commissioned to study the Sun, but it has also managed to discover more than 2,000 comets.

CASSIOPE – Launch: 2013

The Cascade Smallsat and Ionospheric Polar Explorer is a small satellite specifically designed to gather data on solar storms that affect the Earth's upper atmosphere and cause auroras as well as magnetic interference.

SST – Launch: 2003

The Spitzer Space Telescope observatory is unusual as it has a heliocentric orbit, slowly drifting away from Earth. In its extensive studies of stars, the SST has discovered space weather on brown dwarfs (very small stars).

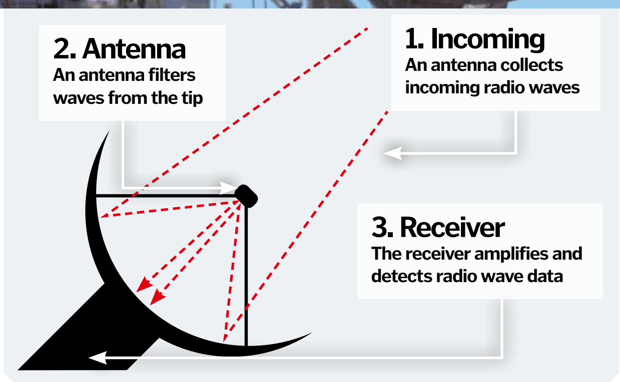
What frequency is a quasar?

Radio telescopes explained

Some objects in space are viewable with the naked eye. Other anomalies such as quasars (the most powerful energy source in the universe – a type of star galaxy) and pulsars (spherical neutron stars) require a radio telescope. These telescopes receive and amplify frequencies from deep space using antennas, and measures their intensity.

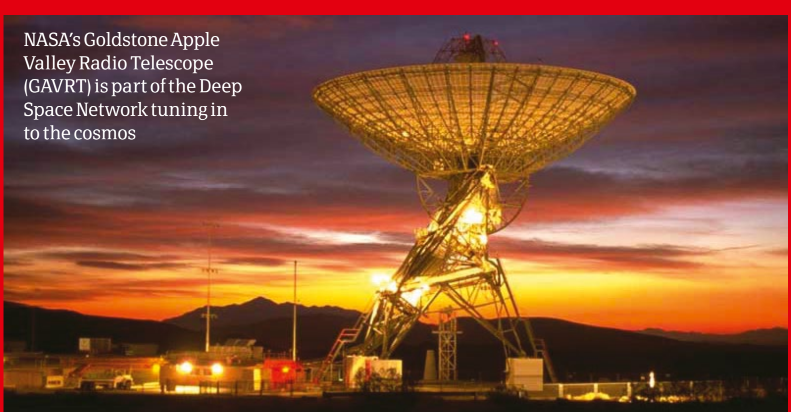
"By studying the intensity of radio frequencies, astronomers can monitor the conditions of space," says Dr Seth Shostak, a senior astronomer at the SETI Institute. "Radio waves are not hindered by gas and dust between stars, so you can 'look' straight through a galaxy to the other side. Quasars were found because of radio telescopes."

According to Dr Shostak, a radio telescope uses a very low-noise amplifier that collects radio waves, themselves collected using massive antennas. The signal passes through the antenna, spreads through a filtering system, and breaks into thousands of frequency channels – a bit like a Doppler satellite that measures the speed of frequencies.



Listening in to the universe

By translating electromagnetic waves into sounds we can hear the 'silence' of space


NASA's Goldstone Apple Valley Radio Telescope (GAVRT) is part of the Deep Space Network tuning in to the cosmos

Sound waves are pressure waves, which cannot travel through a vacuum, so sounds can't actually be heard in the cosmos, however what the universe is brimming with is electromagnetic radiation. We are all familiar with technology that converts radio waves into audible sounds, and similar equipment is being used to listen to what is going on in space. The human ear is so good at detecting audio patterns that, by listening to an audible version of the electromagnetic radiation received by telescopes, astronomers are able to identify information that might have otherwise been missed using visual data alone.

Using radio telescopes, hissing can be heard as solar flares burst from the Sun, while the rhythmic spinning of a pulsar produces clicks like a metronome. Planets also produce their own radio signals and radio noise storms generated by the interaction between Jupiter and its volcanic moon, Io, give off bursts of radio waves that sound like crashing waves and popcorn popping.

Spitzer Space Telescope

The last of NASA's four great observatories, the Spitzer Space Telescope was launched in 2003

Astronomers use Spitzer's orbit and parallaxing to determine the distance of dark planets and black holes

Objects in space radiate heat in the form of infrared energy, but ground-based telescopes cannot detect it due to the Earth's atmosphere. Because the Spitzer Space Telescope orbits around the Sun, it can record this energy in the form of images. The telescope uses three highly sensitive instruments – a camera, a spectrograph and a photometer – that operate on different wavelengths and detect pixels to form pictures.

Infrared telescopes have to be kept very cold (-268°C) in order to function properly. The Spitzer was launched with a liquid helium supply to keep its instruments cold for a minimum of 2.5 years. It is far enough away from the Earth so that it does not pick up infrared energy from our planet, and was fitted with a solar shield to protect it from the Sun's heat. The liquid helium supply was used up on 15 May 2009, but the camera can still detect some infrared wavelengths.

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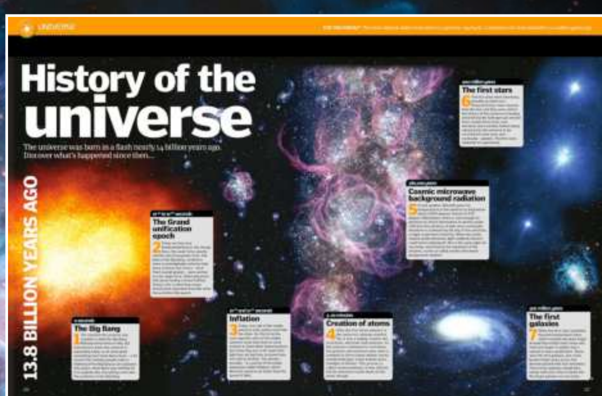

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